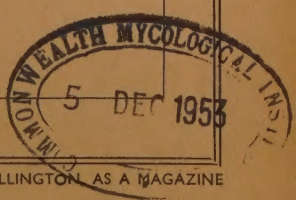
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

NEW ZEALAND
JOURNAL OF SCIENCE
AND
TECHNOLOGY

A. AGRICULTURAL RESEARCH SECTION

VOLUME 35.—SUPPLEMENT 1. SEPT., 1953

Printed for the Department of Scientific and Industrial Research, Wellington,
by
John McIndoe Ltd., Dunedin, N.Z.
SEPTEMBER, 1953



REGISTERED AT G.P.O., WELLINGTON, AS A MAGAZINE

NEW ZEALAND
Journal of Science and Technology
VOLUME 35, Supp 1, 1953
(AGRICULTURAL RESEARCH SECTION)

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NOTICES

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NEW ZEALAND
JOURNAL OF SCIENCE
AND
TECHNOLOGY

Editor: N. A. Marris, M.Sc., B.Com.
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Department of Scientific and Industrial Research, Wellington

VOL. 35. SEC. A 1953 SUPP. 1.

PASTURE GROWTH AND SOIL FERTILITY

I. THE INFLUENCE OF RED AND WHITE CLOVERS, SUPERPHOSPHATE, LIME, AND SHEEP GRAZING, ON PASTURE YIELDS AND BOTANICAL COMPOSITION

P. D. SEARS, Grasslands Division, Department of Scientific and Industrial Research, Palmerston North

(Received for Publication, 24 July 1952)

Summary

(1) In a five-year field trial at Palmerston North, direct and interacting effects of clovers, superphosphate, grazing, and dung and urine, on a mixture of grasses, resulted in wide differences in pasture yields and botanical composition.

(2) Grasses without clovers or dung and urine rapidly deteriorated from ryegrass dominance to a browntop dominant association, yielding annually only about 1800 lb dry matter per acre. With the normal return of dung and urine the yields of these cloverless associations were maintained at higher levels, but there were similar botanical changes.

(3) The addition of white and red clovers to these mixtures increased yields up to 11,000 lb D.M./acre/annum where dung and urine were not returned, and up to 15,000 lb where they were returned.

(4) Without dung and urine, the grass-clover mixtures were dominated by the clovers (mainly white), but where dung and urine were returned, the grasses (mainly ryegrass) were dominant.

(5) No response to lime was obtained in any treatment.

(6) Superphosphate gave responses in growth, but only in the grass-clover mixtures not receiving dung and urine. No response to superphosphate was obtained in any cloverless pasture, or in the grass-clover mixtures receiving the normal return of dung and urine from the mature wethers used in the trial.

(7) Red clover growth was maintained only in the unfertilised mixtures under mowing and not receiving dung and urine. Red clover growth was adversely affected by grazing, by urine, and by superphosphate, either directly or through resultant white clover competition.

(8) There were indications that the sulphur in the superphosphate was of major importance in producing the responses obtained.

INTRODUCTION

IN previous trials at Palmerston North and Lincoln the effects of dung and urine on pasture growth were determined[1,2,3,4,5]. The results, and especially the differences in the ratio of clover to grass growth under different climatic conditions, emphasised the need for further investigation. A series of field experiments was therefore laid down at Palmerston North, Lincoln and Gore to determine specific effects of some of the main factors influencing the growth and composition of mixed pastures.

A review of the literature on the manurial value of dung and urine and on various aspects of losses of nutrients by leaching, by animal development, by poor distribution and by storage, is given by Sears and collaborators[1]. They found that urine applied to a mixed pasture gave quick stimulation to grass growth, and that dung produced an initial clover dominance which changed gradually to one of limited grass dominance after two or three years. They concluded that the return of both dung and urine was essential to the normal development of a high producing mixture of grasses and clovers in the wetter districts of New Zealand. In the drier districts the better summer growth of red clover on areas not receiving dung and urine offset the greater winter and spring growth of the grasses in those which did receive dung and urine.

The value of legumes as the most important agents of nitrogen fixation in the major agricultural areas of the world is too well known to need discussion. An excellent review has been published by Wilson[6] who covers all the important studies made under laboratory, glass-house and field conditions. More recently lysimeter studies have been made by Karraker *et al*[7] over an 11-year period.

They estimated an annual nitrogen addition in the precipitation (42.6 in.) of 10.7 lb per acre, and reported that non-symbiotic nitrogen fixation in a pure bluegrass sward was approximately 33 lb per acre per year.

Symbiotic nitrogen fixation through alfalfa was approximately 223 lb, Korean lespedeza 206 lb, red clover 171 lb, and white clover 148 lb per acre per year. Bluegrass grown in association with each of these legumes produced up to 60 per cent. more than when grown alone. The reverse position applied with the legumes but this was balanced by a greater amount of nitrogen fixation in proportion to the amount of legumes produced when grown with non-legume.

Few workers have measured the effect of clovers in raising pasture production under field conditions. Johnstone-Wallace[8,9,10] compared the total yields, botanical composition and chemical composition of grass pastures with others composed of both grasses and clovers. He concluded that clovers improved pasture productivity in the following ways: (a) they improve the palatability of the herbage; (b) they prevent weed invasion; (c) they produce a better mineral balance in the herbage because of their greater calcium content; (d) they shield the soil in hot weather; and (e) they increase the yield and nitrogen content of the associated grasses.

Trumble, Davies and their associates[11,12,13,14] who worked mainly with annual species, concluded that there was a transfer of nitrogen in the soil from clover to grass only after the clovers had entered their annual period of senescence. They calculated that subterranean clover fixed some 70 lb of nitrogen per ton of dried herbage. Of this amount, approximately 15 lb passed directly into the soil from the roots, the remaining 55 lb being in the herbage and capable of being transferred to the soil through the grazing animal. They observed that applications of superphosphate to soils low in phosphate gave a primary clover response, which was followed by good grass growth, and that this grass growth was sustained only by further superphosphate applications. They concluded that the grasses competed strongly with the clovers for phosphate at the higher soil nitrogen levels.

Although Stapledon[15,16,17] made many observations on the value of clovers, there are few publications from Great Britain on quantitative aspects of the subject. Roberts[19] and Jones[20], however, both recorded herbage and live weight increases of over 25 per cent. when white clover was included in sown pasture mixtures, even though in both of these trials, considerable volunteer white clover appeared in the control areas.

Quantitative results from New Zealand are equally scarce, and limited to a few small-scale trials. Cockayne[21], in discussing cocksfoot seed production, quoted increases of over 100 per cent. in yield when white clover was included in the mixture. He also commented on the relationship between the effects of applied phosphate, the clover content of the pasture and animal droppings. Levy and Gorman[22] measured increases of over 100 per cent. in total green herbage due to the inclusion of New Zealand No. 1 White Clover in ryegrass plots.

In this and succeeding papers of the same series are reported results of trials at Palmerston North, Lincoln and Gore designed to measure the value of red and white clovers in pastures, the effects of superphosphate and lime on swards with and without clovers, and the modification of these effects due to the animal in relation to defoliation, return of droppings, and treading. This paper describes changes in yield and botanical composition; Part II deals with chemical composition in respect to nitrogen, phosphorus, potassium and calcium; Part III deals with soil structure and composition, and earthworm populations; Part IV deals with soil fertility changes as measured by growth of subsequent crops; Part V reports results of separate trials on adjacent areas dealing with the effects of added nitrogenous fertilisers and of night grazings, with their associated differential returns of dung and urine; Parts I-V all deal with the main trial at Palmerston North! Part VI gives the results from Lincoln and Gore; Part VII discusses all the results and their application to farming conditions within New Zealand.

EXPERIMENTAL METHODS

The experimental area was situated on the main Grasslands Division Station at Palmerston North, on the penultimate terrace of the Manawatu River. The ground is level and the soil is classified as Manawatu Silt Loam, a recent type of high fertility with little

profile development. Five years previously the whole area, of which the plots form a small part, had been converted from old orchard to pasture. Following two years under sheep grazing it was used for growing spaced inter-cultivated ryegrass plants which were grazed by sheep. During this latter period no unevenness in fertility had been observed. The soil structure at the end of the three-year period was poor, presumably as a result of the continued cultivations.

Layout and Procedure

The experiment consisted of four main treatments within each of which were six sub-treatments. The main treatments were:

A. Pasture mown and herbage discarded. No application of dung and urine (Mowing N.R.).

B. Pasture mown and herbage discarded. Dung and urine applied in proportion to the herbage yield (Mowing F.R.).

C. Pasture grazed. Dung and urine withheld (Grazing N.R.).

D. Pasture grazed. Dung and urine applied in proportion to the herbage yield (Grazing F.R.).

(All mowing and grazing was done when the tallest pasture was at the 4-6 inch stage.)

For convenience Main Treatments A and B will be called the mowing series, and Main Treatments C and D the grazing series. Similarly Main Treatments A and C will be called the N.R. series and B and D the F.R. series.

Treatments C and D were fenced as separate paddocks each of 1/10th acre, and A and B were combined in another fenced area of the same size. The siting of these main treatments was randomised, but with the limitation that Treatments A and B were placed together, and were each half the size of Treatments C and D. This was done to ensure that sufficient dung and urine would be available from paddock C to apply to B.

In each of the main treatments, sub-treatments were laid down with different combinations of seed mixture and fertiliser as follows:

Sub-treatment	1	Grasses	alone		No	fertiliser		
„	2	„	+	clovers	„	„		
„	3	„	+	„	+	superphosphate		
„	4	„	+	„	+	lime		
„	5	„	+	„	+	superphosphate	+	lime
„	6	„	alone		+	„	+	„

Sub-treatments 1 and 6 were kept free of volunteer clovers by hand weeding throughout the trial.

The plot layout within each paddock was of simple design, consisting of triplicate blocks of plots in the grazing series, and of duplicate blocks in the mowing series. The plots in each of these

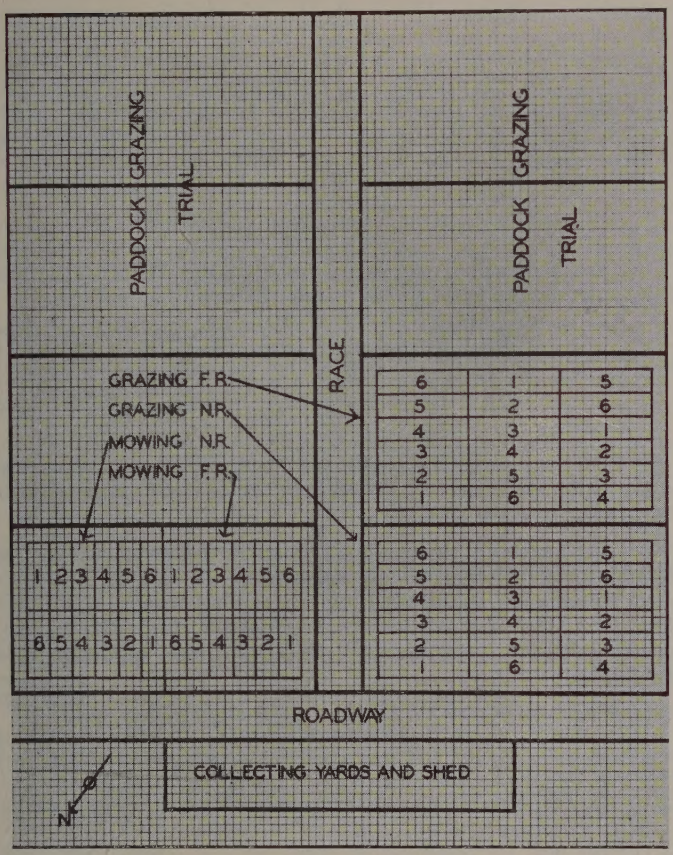

FIG. 1. Experimental layout.

blocks were placed in a regular sequence as shown in Fig. 1. This regular arrangement of the plots was followed because of the complexity of the field work involving cutting, fertilising and the return of dung and urine. Such a regular arrangement prevents a valid statistical estimate of errors, and limits the attention which should be paid to small differences; but it was considered at the commencement of the trial that it would be best to use such a simple pattern because of the reduced possibilities of errors in the field work.

The plots in the grazing series were each 29 ft x 6 ft, and those in the mowing series, 17 ft x 6 ft. Each plot was separated from adjacent plots and headlands by shallow trenches 6 in. wide. This division served to define the plots for cutting and fertilising, and to minimise any lateral effects of plot treatments.

The experimental area was ploughed and surface cultivated during the summer of 1945/46 and sown in March 1946. The mixture of grasses sown was:

Species	Quantity sown per acre (lb)
N.Z. pedigree short rotation ryegrass[23] *(Lolium perenne* × *L. italicum)*	15
N.Z. pedigree perennial ryegrass *(L. perenne)*	20
N.Z. certified cocksfoot *(Dactylis glomerata)*	8
N.Z. certified timothy *(Phleum pratense)*	4
N.Z. browntop *(Agrostis tenuis)*	5
Chewing's fescue *(Festuca rubra* var. *fallax)*	10
Crested dogstail *(Cynosurus cristatus)*	2
Total	64

This grass mixture was sown on all plots. Where appropriate, the following clovers were added to the mixture:

Species of clover	Quantity sown per acre (lb)
Pedigree N.Z. white clover *(Trifolium repens)*	3
Pedigree N.Z. Montgomery red clover *(T. pratense)*	3
Total	6

The headlands surrounding the plots were sown with a mixture of browntop and Chewing's fescue and kept under close mowing throughout the trial.

For the fertiliser applications, the plan followed was to apply to the appropriate plots sufficient superphosphate and/or lime to equal the total amounts of P and Ca removed in the herbage of the *highest* yielding plot. These quantities were calculated from the yields and chemical analyses of the herbage. Details of the applications made are as follows:

Date of Application	Quantity per acre (cwt)	
	Superphosphate	Carbonate of lime
27 March 1946	3	10
13 March 1947	6	10
12 March 1948	3	—
7 July 1948	—	6
8 August 1948	3	—
15 October 1948	3	—
4 April 1949	4	—
14 October 1949	4	—
9 March 1950	3	10

The approximate quantities required for the initial dressings had been calculated from the data of the previous grazing trial at Palmerston North[2].

All treatments were commenced in May 1946, after an initial trimming cut. The mowing and grazing series were then both continued until the end of August 1950, when the grazing series were ploughed, cultivated and sown with rape. After the main cut and the recovery growth of this rape crop had been harvested (March 1951), the area was again cultivated and immediately sown with Italian ryegrass. In October 1951, after the second cut from the ryegrass, another rape crop was sown, using the same line of seed and methods as before. Great care was taken in all these cultivations to avoid plot-to-plot transfer, and only the central area of each plot was measured. A similar cropping programme using rape and maize was imposed on the mowing series in 1951. Details of the cropping programmes will be given in Part IV.

Dung and Urine Collection and Return

Adult sheep fitted with the harness and equipment described by Sears and Goodall[24] were used throughout the trial. For the first year the dung and urine passed during each grazing were collected and mixed together in large drums. This was then spread evenly in proportion to the mean D.M. Yields of each treatment, the yield determinations being made during the periods of grazing.

Subsequently, the urine was returned in proportion to the yields of nitrogen in the herbage, while the dung return was continued in proportion to the D.M. yield. After the first year the dung was dried and ground before being returned, while the urine was returned without any attempt at *evenness* of distribution. The reasons for these changes are discussed later.

Herbage Measurement

In the grazing series, herbage yields were determined just prior to each grazing by mowing down to the height expected at the end of each grazing. A strip 2 ft wide was mown from each plot, and after sampling, the balance of the mown herbage was returned for the grazing sheep to consume with the uncut pasture growth. In the mowing series all the herbage was mown to the same height, measured and discarded.

In both the mowing and grazing series, samples for dry-matter determinations for both botanical analyses were drawn immediately after weighing in the field. For the dry matter determinations, sub-samples of 250 g from each plot were dried in a forced draught oven at 170°-180° F. Botanical analyses were made on the fresh herbage, the separate species being dried and the percentage composition calculated on the dry-weight basis. These analyses were made on duplicate samples drawn from the bulking of replicate plot samples. The weight of the samples of fresh herbage dissected varied between 15 g and 500 g, depending on length of herbage.

Comments on Experimental Procedure.

Differences between the main treatments have only the significance which can be given to comparisons between single paddocks. This applies to overall comparisons of the effects of mowing and grazing, but for the gross effects of dung and urine it is correct to take the combined data of the mowing and grazing series as valid estimates, even though there was restriction of randomisation in the siting of the mowing series. Further, there are considerable interactions between the defoliation methods and the performance of some of the species, so that examination of gross effects of main treatments must be accompanied by consideration of data from the separate paddocks to demonstrate these interactions.

Restrictions apply also to the comparisons of sub-treatments within each of the four main treatments, due to lack of plot randomisation. However, it will be seen that for the most part the effects of different treatments were large, while there were few inconsistencies within any paddock.

The bulking of samples from replicate plots for botanical analysis limits the significance which can be attached to differences in botanical composition, but this was unavoidable with the staff available.

Nevertheless, the annual botanical figures in the tables are derived from 12 to 18 separate analyses and should therefore be an adequate estimate of the true position. Strong evidence that this is so, will be seen in the close agreement in species yields between the limed and unlimed plots in the N.R. series, and between all Sub-treatments 2-5 in the F.R. series. The lack of response to lime in any of the treatments and the non-response of superphosphate in F.R. series allows a useful check on the total botanical analyses and on the field measurements. For this purpose the sub-treatments are grouped in Table IV, in which a very close agreement between the appropriate sub-treatments can readily be seen.

The application of amounts of fertiliser equivalent to the quantity of nutrients removed in the herbage from the highest producing plot is open to criticism. No allowance was made for losses by fixation and leaching. Such losses could vary from plot to plot and so make it incorrect to assume that, for instance, phosphated plots were not limited for phosphorus. There is, however, no reason to believe that these limitations seriously affect the main conclusions drawn from the trial.

The advantages and disadvantages of the technique whereby dung and urine are collected from animals grazing a series of different plots and returned to each treatment in proportion to yield of D.M., have already been discussed in relation to other techniques used in the measurement of pasture production[25]. The relevant points for this trial are as follows:

(i) Since large differences developed in the chemical composition of the herbage from different treatments, it was obvious by the end of the first year of the trial that low-producing plots were receiving more nitrogen than was justified by their yield of nitrogen in the herbage. At this stage, an alteration was made so that urine was returned on the basis of nitrogen removed from each treatment in the clippings, instead of on the basis of D.M. yields. The return of dung in proportion to D.M. yield was continued because digestibility values were not available, and because there were only relatively small differences between treatments in calcium and phosphorus levels in the herbage. More information is required before the validity of this compromise can be properly assessed.

(ii) There is a considerable difference between the even distribution of urine from a watering can and the localisation of urine as it is normally voided in the field by a grazing animal. Growth at the centre of a urine patch is often severely retarded, with the intensity of effect fading out to the margin. Over most of the patch the clover is severely checked, probably due both to direct toxity of some component of the urine, and to the competition from stimulated grass growth. Where clovers tend to grow strongly, the concentration of urine in patches results in a higher ratio of grass to clover than does even distribution from a watering can. There was in general a slightly lower grass-to-clover ratio in the F.R. series than in surrounding grazed areas. It is

considered that the even distribution of urine as well as the loss of some nitrogen from urine during the two to three day collection periods both contributed to this, but in addition there was probably a depressing effect on the grass growth in the plots due to mowing procedure. In the grazing series it was often noticed that the mown strips did not recover in grass growth as rapidly as the grazed areas. This could have been due to the animals regrazing the recovery growth, and thus unduly damaging the ryegrass plants, which are the most rapid to send out new leaf growth after defoliation.

(iii) For ease of handling, dung was dried and ground. It was then distributed evenly over the plots to prevent subsequent irregular grazing. The even spread of dung nutrients is in marked contrast to what occurs in normal grazing where they are concentrated on small areas. It is felt, however, that this should not seriously affect growth over a long period, because of the high earthworm populations in the soils of the high producing plots. Such high earthworm populations rapidly eat all dung voided on the pasture and must aid considerably in effecting an even re-distribution of the dung nutrients through the soil. Any extreme localisation of dung nutrients (such as occurs in normal grazing) would last longer and probably be of more significance on unproductive pastures, with their associated low earthworm populations, than on high production pastures. Oven drying of the dung has a possible added disadvantage of some loss of nitrogen during the actual drying process. For instance, Lancaster[26] in metabolism trials at Ruakura, New Zealand, has found losses of up to 10 per cent. of the nitrogen in sheep faeces, during oven drying.

(iv) The application of dung and urine *equally* to the plots within a sub-treatment, rather than in proportion to the *individual* plot yields could result in an abnormally low coefficient of variability, and may thus lead to over-emphasis on small differences. Throughout these trials, however, no differences have been reported unless they are large and consistent.

CLIMATIC CONDITIONS

Climate is one of the most important factors in the high productivity of New Zealand's pastures. In Table I is given a summary of air temperature and rainfall by seasons at Palmerston North for the period 1946-50. Full climatological data from the weather station on the area are available from the official records[27].

TABLE I. AVERAGE AIR TEMPERATURES AND RAINFALL BY SEASONS FOR THE YEARS 1946-50: PALMERSTON NORTH

Season	Screen air temperatures °F					Seasonal Rainfall	
	Mean Daily Max.	Mean Daily Min.	Mean Daily	Max. Recorded	Min. Recorded	Total (in.)	Rainy days
Spring (Sep-Nov)	61.0	46.0	53.5	76.7	29.8	9.73	52
Summer (Dec-Feb)	70.2	51.8	61.0	85.0	36.0	8.25	34
Autumn (Mar-May)	64.3	47.7	56.0	80.0	29.8	8.21	36
Winter (June-Aug)	55.0	40.7	47.8	68.0	25.2	13.37	42
Annual Averages and Totals	62.6	46.5	54.5	85.0	25.2	39.56	164

The Table demonstrates clearly the suitability of the locality for high pasture production. Neither temperatures nor soil moisture are excessively limiting factors for pasture production, and the fluctuations between seasons are much lower than usually experienced in most other countries. The weather conditions during the trial period were typical of the normal experienced at Palmerston North. The only marked departures from the average were that the summers of 1947 and 1950 were drier, and the winter of 1947 and the spring of 1951 (during the second cropping period) were much wetter than normal. It is considered that these climatic differences were not sufficient to affect the trial sufficiently to treat any of the results as being other than normal for the experimental area.

TABLE II. HERBAGE YIELDS FOR THE FIRST HALF YEAR AND THE FOLLOWING ANNUAL PERIODS
(In lb of dry matter per acre)

Main Treatment	Growth Period	Sub-treatments						95% Confidence Limits *
		1 Grasses alone No Fert-iliser	2 Grasses + Clovers No Fert-iliser	3 Grasses + Clovers + Super	4 Grasses + Clovers + Lime	5 Grasses + Clovers + Lime + Super	6 Grasses alone + Lime + Super	
A Mowing N.R.	** 1946	1304	1280	1403	1321	1263	1226	± 110
	1946-47	2934	10293	11658	11178	11976	2651	± 820
	1947-48	1700	9824	11089	10924	11500	1830	"
	1948-49	2036	9666	12045	10154	12232	2279	"
	1949-50	1775	8634	11037	8952	11402	1884	"
B Mowing F.R.	1946	1146	1225	1257	1310	1351	1443	± 110
	1946-47	4448	11937	11975	11592	12129	4818	± 1930
	1947-48	4427	13732	13324	12874	13245	4231	"
	1948-49	5963	15487	15241	15247	14875	5947	"
	1949-50	4832	14528	14742	13290	14214	5275	"
C Grazing N.R.	1946	974	1018	1070	1060	1088	1054	± 110
	1946-47	2950	7906	8328	8237	8636	3365	± 1150
	1947-48	1288	7078	7486	7076	7963	1230	"
	1948-49	1066	8802	10931	8081	10761	1170	"
	1949-50	1717	7454	10481	6794	9812	1754	"
D Grazing F.R.	1946	1143	1138	1144	1182	1234	1244	± 110
	1946-47	4614	9598	9523	9389	9545	4545	± 490
	1947-48	2213	9641	9723	9691	10136	2330	"
	1948-49	2152	12764	12596	12320	12498	2346	"
	1949-50	2935	12763	13954	12402	13056	2764	"

* 95% Confidence limits within each paddock based on all plot yields for the first half-year period. For the next four-year period the limits were calculated only from the data for Sub-treatments 2 - 5 in each treatment.

** Periods shown are for the first six months from March to August 1946, and then for the annual periods ending 31 August each year.

RESULTS AND DISCUSSION

Total Dry Matter Production

Table II gives the annual D.M. yields for all treatments, together with the 95 per cent. Confidence Limits, which have been calculated on the basis of full randomisation within each block, using for this purpose the complete 4-year data for the main treatments considered separately. This is of course not strictly valid, but the calculations are presented as the best estimate of error possible for this layout. Only Sub-treatments 2-5 were considered because of the large differences which developed between this group and Sub-treatments 1 and 6 in all main treatments, after the first six months. In no main treatment were there any marked differences in pasture yield and composition between the cloverless sub-treatments.

It is emphasised that direct comparisons cannot be made between the yields of the mowing and grazing series because growth was not measured on the latter during the actual grazing periods. Table III summarises the yield information in Table II by calculating annual and total yields for all treatments as percentages of Sub-treatment 2.

TABLE III. RELATIVE YIELDS OF DRY MATTER (All yields relative to Sub-treatment 2 = 100 for each period and for each main treatment)

Main Treatment	Growth Period	Defoliation by	Sub-treatments					
			1 Grasses alone No Fertiliser	2 Grasses + Clovers No Fertiliser	3 Grasses + Clovers + Super	4 Grasses + Clovers + Lime	5 Grasses + Clovers + Super + Lime	6 Grasses alone + Super + Lime
No Return of Dung and Urine	1946-47	Mowing	26.8	100	106.7	102.4	109.7	24.1
		Grazing	37.3	100	105.4	104.2	109.3	42.5
		Average	32.1	100	106.0	103.3	109.5	33.3
	1947-48	Mowing	17.3	100	112.8	111.2	117.0	18.6
		Grazing	18.2	100	105.8	100.0	112.2	17.3
		Average	17.8	100	109.3	105.6	114.6	18.0
	1948-49	Mowing	21.1	100	124.6	104.9	126.4	23.5
		Grazing	12.0	100	124.1	91.8	122.2	13.3
		Average	16.6	100	124.4	98.4	124.3	18.9
	1949-50	Mowing	20.6	100	128.0	103.6	132.0	21.8
		Grazing	23.1	100	140.6	91.1	131.6	23.4
		Average	21.8	100	134.3	97.3	131.8	22.6
	Total 1946-50	Mowing	21.6	100	117.4	105.4	120.6	22.1
		Grazing	22.5	100	119.2	96.7	119.0	24.0
		Average	22.1	100	118.3	101.0	119.8	23.1
Full Return of Dung and Urine	1946-47	Mowing	37.3	100	100.4	97.2	101.6	40.3
		Grazing	48.0	100	99.1	97.8	99.5	47.4
		Average	42.6	100	99.8	97.5	100.6	43.8
	1947-48	Mowing	32.3	100	97.0	93.7	96.5	30.8
		Grazing	22.9	100	100.8	100.5	105.2	24.0
		Average	27.6	100	98.9	97.1	100.9	27.4
	1948-49	Mowing	38.5	100	98.3	98.3	96.0	38.4
		Grazing	16.8	100	98.7	96.5	97.9	18.4
		Average	27.7	100	98.5	97.4	96.9	28.4
	1949-50	Mowing	33.2	100	101.4	91.5	97.8	36.0
		Grazing	23.1	100	109.5	97.3	102.5	21.7
		Average	28.2	100	105.5	94.4	100.2	28.9
	Total 1946-50	Mowing	35.3	100	99.3	95.2	97.8	36.3
		Grazing	26.6	100	102.3	97.9	101.1	26.7
		Average	30.9	100	100.8	96.6	99.5	31.5

From Tables II and III it is seen that:

(i) During the first six months all plots produced similar weights of herbage. This is an indication that the original area was reasonably uniform as judged by pasture growth.

(ii) The general level of the Coefficient of Variation of the total yields is approximately 3 per cent. with that of the Mowing F.R. treatment rising to approximately 5 per cent. Between November 1949 and May 1950, Plots 4 and 5 in one replicate of that treatment developed a marked yellow appearance and decreased markedly in yield. No explanation could be offered for this condition which later disappeared, but it was sufficient to cause an increase in the Coefficient of Variability to 5 per cent. for the treatment as a whole.
(iii) The most important single factor affecting yields was the presence of clovers. The yield of all cloverless plots was poor and varied from less than 20 per cent. to 38 per cent. of the corresponding grass-clover yields.

(iv) Superphosphate and lime caused no increase in yield on pure-grass swards.

(v) In the N.R. series, plots receiving superphosphate always out-yielded those receiving none. These differences increased as the trial proceeded. In the F.R. series no response was obtained with superphosphate.

(vi) There was no significant lime response in any treatment, although the depression in yield in the Grazing N.R. treatment, during the later years is perhaps worthy of note.

(vii) In the Mowing F.R. treatment, Sub-treatments 1 and 6 maintained a fairly steady annual production without the rapid decrease shown by the corresponding N.R. plots. On the other hand, corresponding plots in the Grazing F.R. treatment showed a decline which was nearer to that in the Grazing N.R. treatment.

Species Yields

The total yields for the 4-year period together with the yields of component species, and their percentage contributions, are recorded for all treatments in Table IV. The annual changes in botanical composition are shown in Table V and are also shown graphically in Fig. 2, for part of the Mowing series. Sub-treatments 1, 2, and 3 only are presented as Sub-treatments 6, 4 and 5 respectively correspond so closely with these that their separate presentation is not justified. Similarly, although there are some interesting differences between the mowing and grazing series, they are not of sufficient degree to warrant detailed presentation of the annual data. In Fig. 3 are shown the mean annual species yields of all sub-treatments in the mowing series, for the final two-year period when the treatment effects had become stabilised.

Details of species yields for the first 6-month period are not presented because there were no definite differences between any of

the treatments. For all plots, the approximate species composition was: ryegrass, 73 per cent.; other grasses (mainly *Poa annua*), 7 per cent.; and weeds (mainly *Coronopus didymus* and *Spergula arvensis*), 20 per cent.; with the clovers contributing, in their appropriate plots, only 1 to 2 per cent. The two weed species are common in autumn sowings on this land, and both disappeared as is usual, after a few months.

TABLE IV. TOTAL AND SPECIES YIELDS OF DRY MATTER FOR THE PERIOD AUGUST 1946 - SEPTEMBER 1950
"Actual yields of D.M./acre on left of each column, percentage composition in brackets."

Main Treatment	Sub-treatment	Total Yields (lb. per acre)	95% Confidence Limits of Total Yields *	Species yields and percentages of total yields (lb./acre)							
				Ryegrass	Browntop	Timothy	Cocksfoot	Dogstail	Other Grasses	White Clover	Red Clover	Other Species
Mowing N.R. A	1	8445	-	3612 (43)	2701 (32)	435 (5)	373 (4)	785 (9)	159 (2)	- (-)	- (-)	380 (5)
	6	8644	-	3194 (37)	2669 (31)	461 (5)	484 (6)	1058 (12)	377 (4)	- (-)	- (-)	401 (5)
	2	39047	± 2080	6817 (17)	4371 (11)	648 (2)	767 (2)	916 (2)	543 (1)	15194(39)	9580 (25)	211 (1)
	4	41208	"	7140 (17)	3003 (7)	598 (2)	1108 (3)	980 (2)	511 (1)	17737(43)	9759 (24)	374 (1)
	3	45829	"	9027 (20)	2834 (6)	565 (1)	2138 (5)	620 (1)	796 (2)	23037(50)	6613 (14)	198 (-)
	5	47110	"	10055 (21)	1751 (4)	1056 (2)	2500 (5)	910 (2)	802 (2)	22170(47)	7700 (16)	166 (-)
Mowing P.R. B	1	19670	-	6995 (36)	5286 (27)	1424 (7)	2113 (11)	1521 (8)	1774 (9)	-	-	557 (3)
	6	20271	-	7640 (38)	5024 (25)	1098 (5)	2839 (14)	1904 (9)	1302 (6)	-	-	464 (2)
	2	55684	± 4130	28161 (51)	262 (1)	1274 (2)	3844 (7)	273 (1)	688 (1)	19591 (35)	1323 (2)	265 (-)
	4	53003	"	24397 (46)	137 (-)	1880 (4)	4509 (9)	224 (-)	824 (2)	19218 (36)	1456 (3)	358 (1)
	3	55282	"	28069 (51)	111 (-)	1533 (3)	3190 (6)	140 (-)	798 (1)	19827 (36)	1405 (2)	209 (-)
	5	54463	"	27476 (50)	111 (-)	1426 (3)	2941 (5)	88 (-)	600 (1)	20335 (37)	1270 (2)	216 (1)
Grazing N.R. C	1	7021	-	3633 (52)	1732 (25)	331 (5)	249 (4)	573 (8)	281 (4)	- (-)	- (-)	222 (3)
	6	7519	-	4097 (55)	1624 (22)	354 (5)	361 (5)	613 (8)	213 (3)	- (-)	- (-)	251 (3)
	2	31240	± 1170	7181 (23)	3403 (11)	690 (2)	858 (3)	430 (1)	457 (1)	14636 (47)	3427 (11)	177 (1)
	4	30188	"	6266 (21)	2721 (9)	958 (3)	1135 (4)	307 (1)	636 (2)	14327 (48)	3551 (12)	286 (1)
	3	37226	"	8893 (24)	2690 (7)	782 (2)	1658 (4)	709 (2)	472 (1)	19540 (53)	2195 (6)	287 (1)
	5	37172	"	10043 (27)	1325 (4)	927 (3)	2743 (7)	598 (1)	460 (2)	18122 (49)	2761 (7)	192 (1)
Grazing P.R. D	1	11914	-	6620 (56)	2419 (20)	657 (6)	583 (5)	707 (6)	516 (4)	- (-)	- (-)	413 (4)
	6	11985	-	6422 (54)	2314 (19)	668 (6)	751 (6)	953 (8)	592 (5)	- (-)	- (-)	285 (2)
	2	44735	± 1020	21967 (49)	195 (-)	995 (2)	947 (2)	109 (-)	863 (2)	18499 (41)	605 (1)	556 (1)
	4	43802	"	21140 (48)	205 (1)	938 (2)	1533 (4)	51 (-)	724 (2)	17811 (41)	833 (2)	566 (1)
	3	45796	"	23894 (52)	217 (1)	1087 (2)	901 (2)	92 (-)	668 (1)	17652 (39)	906 (2)	379 (1)
	5	45235	"	23136 (51)	136 (-)	756 (2)	1101 (2)	55 (-)	584 (1)	18165 (40)	865 (2)	438 (1)

* 95% Confidence limits calculated for each paddock from data for Plots 2 - 5 only.

TABLE V. ANNUAL YIELDS AND SPECIES COMPOSITION OF SUB-TREATMENTS 1, 2 AND 3 OF THE N.R. SERIES, AND OF 1 AND 2 OF THE F.R. SERIES "Actual yields of D.M./acre on left of each column, percentage composition in brackets."

Main Treatment	Sub-treatment	Growth Period	Total Yield D.M. (lb./acre)	Species Yields and Percentages of Total Yields (lb./acre)								
				Ryegrass	Browntop	Timothy	Cocksfoot	Dogstail	Other Grasses	White Clover	Red Clover	Other Species
A Mowing N.R.	1	1946 - 47	2934	2399 (82)	11 (-)	247 (8)	20 (1)	51 (2)	11 (-)	- (-)	- (-)	195 (7)
		1947 - 48	1700	795 (47)	384 (23)	105 (6)	98 (6)	218 (13)	76 (5)	- (-)	- (-)	24 (2)
		1948 - 49	2036	309 (15)	1247 (61)	31 (2)	134 (7)	271 (13)	6 (-)	- (-)	- (-)	38 (2)
		1949 - 50	1775	109 (6)	1059 (60)	52 (3)	121 (7)	245 (14)	66 (4)	- (-)	- (-)	123 (7)
	2	1946 - 47	10923	2736 (25)	51 (-)	180 (2)	48 (-)	42 (-)	115 (1)	3611 (33)	4026 (37)	114 (1)
		1947 - 48	9824	1636 (17)	442 (5)	303 (3)	122 (1)	368 (4)	107 (1)	5330 (54)	1467 (15)	49 (1)
		1948 - 49	9666	1741 (18)	1873 (19)	83 (1)	309 (3)	463 (5)	262 (3)	3264 (34)	1636 (17)	35 (1)
		1949 - 50	8634	704 (8)	2005 (23)	82 (1)	288 (3)	43 (1)	59 (1)	2989 (35)	2451 (28)	13 (-)
	3	1946 - 47	11658	2602 (22)	49 (-)	173 (2)	19 (-)	43 (-)	41 (-)	4996 (43)	3620 (31)	114 (1)
		1947 - 48	11089	1881 (17)	427 (4)	196 (2)	286 (3)	353 (3)	124 (1)	5692 (51)	2076 (19)	54 (1)
		1948 - 49	12045	2405 (20)	1479 (12)	65 (1)	675 (6)	224 (2)	359 (3)	6210 (52)	598 (5)	30 (-)
		1949 - 50	11037	2139 (19)	879 (8)	131 (1)	1158 (11)	Tr. (-)	272 (3)	6139 (56)	319 (3)	- (-)
B Mowing F.R.	1	1946 - 47	4448	3576 (80)	35 (1)	398 (9)	85 (2)	90 (2)	173 (4)	- (-)	- (-)	91 (2)
		1947 - 48	4427	1896 (43)	583 (13)	461 (10)	571 (13)	613 (14)	253 (6)	- (-)	- (-)	50 (1)
		1948 - 49	5963	866 (15)	2275 (38)	295 (5)	821 (14)	618 (10)	910 (15)	- (-)	- (-)	178 (3)
		1949 - 50	4832	657 (14)	2393 (50)	270 (6)	636 (13)	200 (4)	438 (9)	- (-)	- (-)	238 (5)
	2	1946 - 47	11937	5883 (49)	100 (1)	482 (4)	176 (2)	153 (1)	179 (2)	3673 (31)	1168 (10)	123 (1)
		1947 - 48	13732	5208 (38)	100 (1)	379 (3)	927 (7)	87 (1)	115 (1)	6815 (50)	82 (1)	12 (-)
		1948 - 49	15487	9301 (60)	55 (-)	295 (2)	986 (6)	33 (-)	291 (2)	4400 (28)	63 (-)	63 (-)
		1949 - 50	14528	7772 (54)	- (-)	118 (1)	1755 (12)	- (-)	103 (1)	4703 (32)	10 (-)	67 (1)

TABLE V. (Continued)

C Grazing N.R.	1	1946 - 47	2950	2599	(88)	27	(1)	121	(4)	37	(1)	50	(2)	62	(2)	-	(-)	-	(-)	54	(2)
		1947 - 48	1288	681	(53)	225	(17)	126	(10)	47	(4)	134	(11)	41	(3)	-	(-)	-	(-)	34	(3)
		1948 - 49	1066	229	(22)	416	(39)	34	(3)	77	(7)	174	(16)	104	(10)	-	(-)	-	(-)	32	(3)
		1949 - 50	1717	124	(7)	1064	(62)	50	(3)	88	(5)	215	(13)	74	(4)	-	(-)	-	(-)	102	(6)
	2	1946 - 47	7906	3380	(43)	77	(1)	235	(3)	45	(1)	56	(1)	123	(2)	2672	(34)	1231	(16)	87	(1)
		1947 - 48	7078	1010	(14)	309	(4)	143	(2)	130	(2)	199	(3)	17	(-)	4239	(60)	1006	(14)	25	(-)
		1948 - 49	8802	1696	(19)	1382	(16)	182	(2)	254	(3)	132	(1)	104	(1)	4398	(50)	603	(7)	50	(1)
		1949 - 50	7454	1095	(15)	1635	(22)	130	(2)	429	(6)	43	(1)	193	(3)	3327	(45)	587	(8)	15	(-)
	3	1946 - 47	8328	2602	(31)	60	(1)	139	(2)	78	(1)	23	(-)	138	(2)	3673	(44)	1519	(18)	96	(1)
		1947 - 48	7486	1307	(18)	376	(5)	159	(2)	129	(2)	213	(3)	19	(-)	4737	(63)	481	(6)	65	(1)
		1948 - 49	10931	2806	(26)	1245	(11)	159	(2)	382	(4)	369	(3)	80	(1)	5680	(52)	127	(1)	83	(1)
		1949 - 50	10481	2178	(21)	1009	(10)	325	(3)	1069	(10)	104	(1)	235	(2)	5450	(52)	68	(1)	43	(-)
D Grazing F.R.	1	1946 - 47	4614	4005	(87)	14	(-)	214	(5)	67	(2)	56	(1)	141	(3)	-	(-)	-	(-)	117	(3)
		1947 - 48	2213	1379	(62)	199	(9)	184	(8)	110	(5)	249	(11)	35	(2)	-	(-)	-	(-)	57	(3)
		1948 - 49	2152	717	(33)	713	(33)	75	(4)	296	(14)	153	(7)	152	(7)	-	(-)	-	(-)	47	(2)
		1949 - 50	2935	519	(18)	1493	(51)	184	(6)	110	(4)	249	(9)	188	(6)	-	(-)	-	(-)	192	(7)
	2	1946 - 47	9598	5438	(57)	43	(-)	347	(4)	168	(2)	85	(1)	215	(2)	2644	(28)	488	(5)	170	(2)
		1947 - 48	9641	3476	(36)	106	(1)	368	(4)	146	(2)	24	(-)	103	(1)	5102	(53)	117	(1)	199	(2)
		1948 - 49	12764	6996	(55)	46	(-)	161	(1)	251	(2)	-	(-)	345	(3)	4911	(39)	-	(-)	55	(-)
		1949 - 50	12732	6057	(48)	-	(-)	119	(1)	382	(3)	-	(-)	200	(2)	5842	(46)	-	(-)	132	(1)

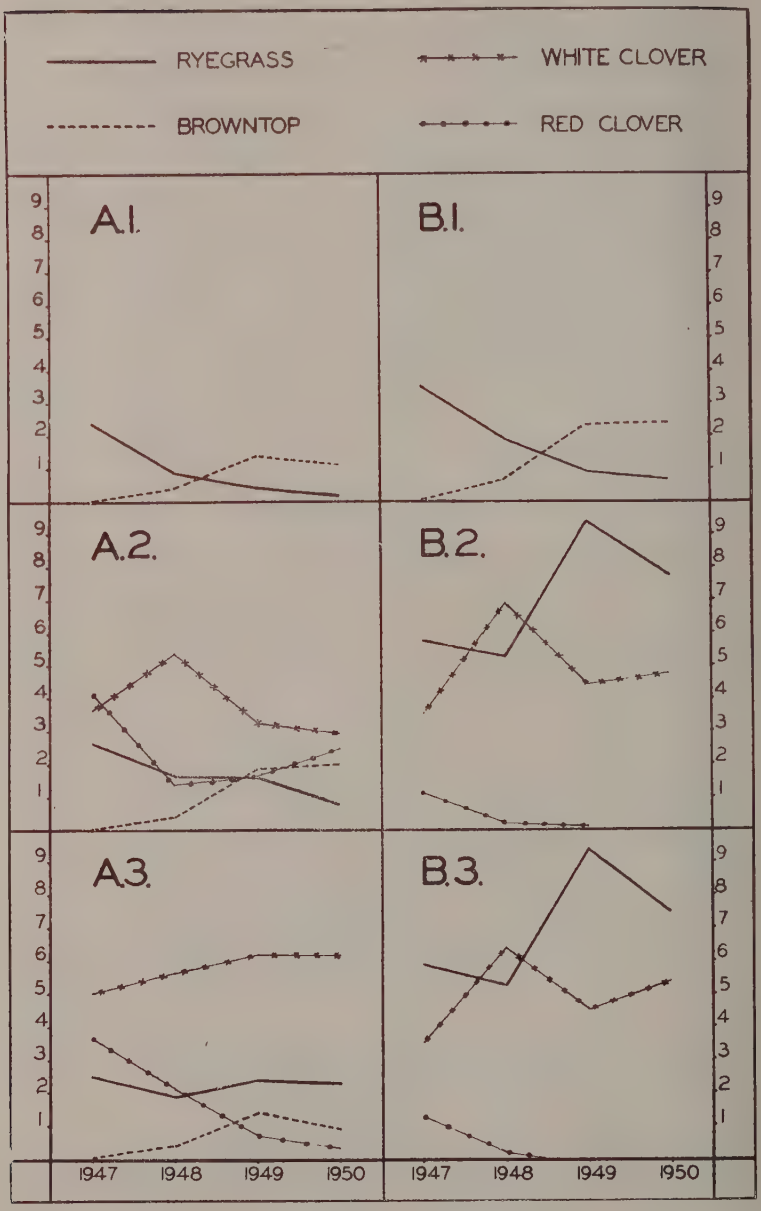

FIG. 2. Main species annual yields (in 000's lb D.M./acre) in Sub-treatments 1, 2 and 3, of the mowing series. A=N.R.; B=F.R. treatment.

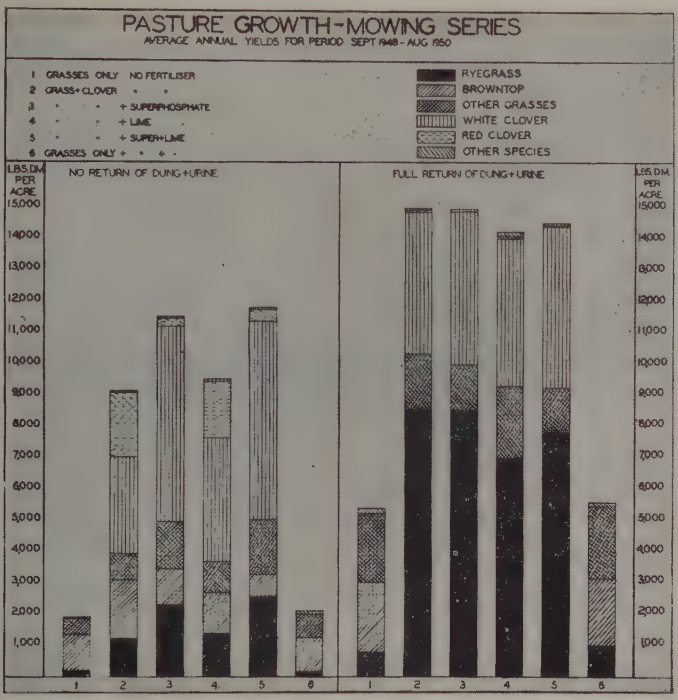

FIG. 3. Annual herbage yields in the mowing series, for the period September 1948 to August, 1950.

Considering the main 4-year period of the trial, the major points of interest in the Mowing N.R. treatments are:

(i) Ryegrass yields declined rapidly in Sub-treatments 1 and 6. They declined more slowly in Sub-treatments 2 and 4, while in Sub-treatments 3 and 5 they were nearly constant.

(ii) Browntop became dominant in Sub-treatments 1 and 6 after two years. The greatest total yield of browntop occurred, however, in Sub-treatments 2 and 4, but browntop did not become dominant in these plots although its percentage contribution to the herbage yield increased as the trial proceeded. The yield of browntop from Treatments 3 and 5 was intermediate between the yields from the other sub-treatments. It rose to a peak in the third year and then declined.

(iii) Timothy was an unimportant constituent in all plots.

(iv) Cocksfoot made a considerable contribution to the yield only in Sub-treatments 3 and 5. In these plots both its yield and its relative production increased throughout the trial.

(v) Crested dogstail contributed significantly to yields only in Sub-treatments 1 and 6. Under other treatments it was always unimportant and after the first two years almost disappeared.

(vi) Other grasses, including *Poa annua, Poa trivialis,* Chewings fescue and Yorkshire fog at no stage assumed much importance, except in the third winter and spring of the trial. At this time, in Sub-treatments 3 and 5 *Poa trivialis* became so strong as to form a dense mat. In the spring of that year there was a lower clover yield from these plots, presumably due to competition from the *Poa trivialis.* Late in the spring all the plots of this series were vigorously raked and closely mown to open up the pasture and to eliminate the *Poa trivialis.* A strong invasion of this species did not recur in any of the plots.

(vii) The yields of white clover in Sub-treatments 2 and 4 declined after the second year, whereas in Sub-treatments 3 and 5 the yield was maintained.

(viii) The total yields of red clover over the 4-year period were lower than those of white clover, being about one half in the unfertilised plots and only a third in the plots fertilised with superphosphate. As the trial progressed the relative yields of the two clovers changed markedly. Initially the yields were approximately equal. In the last years of the trial the yield of red clover was only about 5 per cent. of that of white clover in plots receiving superphosphate, whereas the two clovers were almost equal in production in the unfertilised plots. Red clover changed in annual yield inversely to white clover.

(ix) Weeds contributed little to the herbage yield after the first year except in Sub-treatments 1 and 6. In both these plots there was a considerable cover of *Hypochaeris radicata, Leontodon hispidus* and *Plantago major* with some *Anagallis arvensis* and *Bellis perennis.*

The changing yields of the different species give an indication of how the plant associations were modified by the various sub-treatments. Initially, ryegrass was dominant in all plots. Sub-treatments 1 and 6 then rapidly deteriorated and became swards of browntop, crested dogstail and flatweeds. In Sub-treatments 2 and 4, white clover became dominant and there developed a high yielding association mainly of white clover, ryegrass, red clover and browntop, but the former two species declining, and the latter two increasing in amount. In Sub-treatments 3 and 5, white clover remained dominant and the most highly productive association of this series was maintained. The main species in this association were white clover, ryegrass, and cocksfoot, with browntop of much less importance. Red clover was markedly reduced after the first two years of the trial.

The main points which rise from a consideration of the yields of different species under the Mowing F.R. treatment are as follows:

(i) Ryegrass yields were greater than in comparable plots in the Mowing N.R. series, the increase being double in Sub-treatments 1 and 6, threefold in Sub-treatments 3 and 5 and fourfold in Sub-treatments 2 and 4. A decline in ryegrass yield is again seen in Sub-treatments 1 and 6, although it was slower than in the Mowing N.R. treatment. Under other sub-treatments the yield of ryegrass rose to a high peak and then declined in the final year, at which time cocksfoot was rising to an obvious position.

(ii) Browntop was of importance only in Sub-treatments 1 and 6 where it rapidly increased to dominance as the ryegrass decreased in vigour.

(iii) In all plots the total production of timothy was of a low order, namely between 1000 and 2000 lb of dry matter per acre for the 4-year period.

(iv) Cocksfoot made an important contribution to the herbage yield of all plots after the second year. In Sub-treatments 1 and 6 its yield finally equalled that of ryegrass. Sub-treatments 2, 3, 4 and 5 showed no differences in cocksfoot yields.

(v) The yield of crested dogstail declined in all plots, probably because there was no opportunity for reseeding. In Sub-treatments 1 and 6 the yield increased during the first two years and then declined. In other plots there was never more than a trace of crested dogstail.

(vi) Chewings fescue in Sub-treatments 1 and 6 tended to form a dense turf but the total yield of mown herbage of this species was relatively small. It was included in "other grasses" together with small amounts of *Poa annua* and *Holcus lanatus*.

(vii) The yield of white clover for the 4-year period was nearly the same for all sub-treatments and its total production was not greatly different from that in Sub-treatments 3 and 5 of the Mowing N.R. treatment although it was obviously lower in the final two years when there was a marked increase in the N.R. pair.

(viii) In the first year the yield of red clover was only about half that in the Mowing N.R. treatment. Thereafter the yield rapidly declined and became negligible after the second year.

(ix) The growth of weed species was slightly greater than that in the Mowing N.R. treatment.

The changes in the botanical composition of the herbage occurring in the Mowing F.R. treatment differed in many respects from those observed in the Mowing N.R. treatment. In Sub-treatments 1 and 6 the change to browntop dominance occurred more slowly, and ryegrass and cocksfoot were subdominant. In other sub-treatments ryegrass remained as the dominant species and the relative importance of its yield was much greater than in the Mowing N.R. treatment. On the contrary, the yield of red clover was much lower. The total yield of white clover was about the same in the two treatments, but in the Mowing F.R. treatment it represented a smaller proportion of the total yield because of the greater yield of the grasses, especially ryegrass.

A comparison between the mowing and grazing series brings out several points of interest. A major difference was the greater red-clover yield in the N.R. series under mowing. This was doubtless due to greater damage being caused to the single crowned red clover plants by the treading and nibbling of the animals, than by the cutting and rolling of the mower.

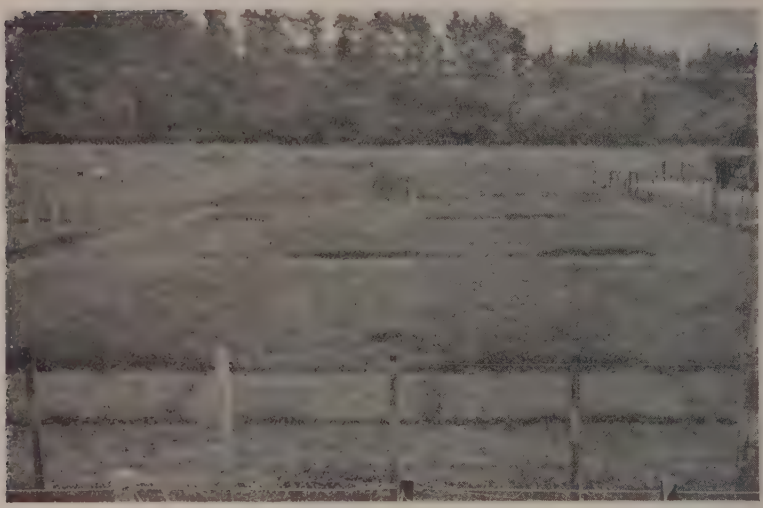

Fig. 4. The grazing N.R. paddock ready for cutting and grazing in the late spring of 1949. Clearly visible are the response to superphosphate and the lime depression (at that time) on the grass-clover plots (see layout Fig. 1). Note the stemmy and low production on the cloverless plots. The near end of each plot was cut to give clearer photographic comparisons.

Fig. 5. Plots on the Mowing N. R. paddock in the early summer of 1950. The plots receiving superphosphate (left front) had much greater white clover and grass growth than the grass-clover plots without superphosphate, which were red clover dominant at this stage.

In the Mowing N.R. treatment, red clover grew better on unfertilised plots than on those which were fertilised, and consequently there were no large differences in herbage yield between plots sown with both grasses and clovers.

In the Grazing N.R. treatment, the yield from red clover was lower and was insufficient to equalise the production of fertilised and unfertilised plots. It would therefore be expected that the percentage increase in herbage yield due to superphosphate on the Grazing N.R. treatment would be greater than on the Mowing N.R. treatment. However, there was actually a lower percentage response of white clover to the applications of superphosphate on the Grazing N.R. treatment, possibly due to similar grazing injuries to the white clover plant. The percentage increases due to superphosphate in the two separate series of N.R. plots are very similar.

The effect of heavy treading and grazing on the grass species is indicated by a comparison of the performance of cocksfoot, browntop and *Poa trivialis* under mowing and under grazing. Cocksfoot grew more strongly on all plots of the mowing series, and there was similarly a greater growth of browntop in Treatments 1 and 6 under mowing. *Poa trivialis* became important only in the mown plots and was almost absent from those which were grazed. In the relatively undisturbed sward formed where the pasture was mown, growing points would be safe from injury, whereas under grazing these parts would often be damaged by treading and close grazing.

Ground Cover Changes

Table VI shows ground cover as measured by the single storey point analysis method of determining botanical composition[28]. Data are given for only two analyses, one at a very early stage of the trial and the other three years later. Several other analyses were made at intermediate stages but as these do not give any additional information they have not been presented. Again for conciseness in presentation, data from Sub-treatments 1, 2 and 3 only are presented in the table. The percentage ground cover was determined by taking 100 points, the analyses being made shortly after mowing in all cases, when the average growth height was about $\frac{1}{2}$ in. on the grass plots and 1-1$\frac{1}{2}$ in. on the grass-clover associations.

The data show the same general pattern of change in major species as is provided by dissection of the cut herbage. They also demonstrate very clearly the contribution made to ground cover by low production species of prostrate habit. Browntop and Chewings fescue contribute only in minor degree to herbage yield, but their effect on ground cover is very marked in the second analyses. Although *Poa trivialis* is not shown separately, it also contributed noticeably to ground cover at certain seasons on the Mowing N.R. plots.

The differential response of white clover under mowing and grazing can best be seen by comparing Sub-treatment 5 N.R. with 5 F.R. in which no complication arises from red clover. Under mowing, white clover covers more ground than under grazing and it is probable that this is the result of more intense defoliation by the animal than by the mower.

TABLE VI. PERCENTAGES OF GROUND COVERED BY SPECIES IN REPRESENTATIVE SUB-TREATMENTS AT EARLY AND LATE STAGES OF THE EXPERIMENTAL PERIOD
(All figures shown are the simple means from 100 points per plot.)

Main Treatment	Date of Analysis	Sub-treatment	Percentage of ground covered by										
			Ryegrass	Browntop	Timothy	Cocksfoot	Dogstail	Chewings fescue	Other grasses	White clover	Red clover	Other species	Bare ground
A Mowing N.R.	5/8/47	1	63	27	16	5	19	-	-	-	-	-	10
		2	28	9	5	3	8	-	1	54	11	2	1
		3	36	6	5	3	4	-	2	50	9	2	-
	21/8/50	1	3	80	1	4	15	15	2	-	-	6	3
		2	15	68	2	16	2	2	3	45	25	1	-
		3	38	36	4	18	-	-	4	90	1	-	-
B Mowing F.R.	5/8/47	1	73	38	19	12	29	-	5	-	-	9	5
		2	66	5	7	3	3	-	5	53	-	2	-
		3	65	2	5	6	-	-	3	54	1	2	-
	21/8/50	1	7	73	1	17	8	37	10	-	-	7	-
		2	84	-	5	23	-	-	1	91	-	-	-
		3	83	-	3	16	-	-	5	92	-	-	-
C Grazing N.R.	5/8/47	1	44	40	7	6	4	-	1	-	-	5	3
		2	45	7	7	5	1	-	-	68	3	2	1
		3	45	9	4	4	-	-	-	59	2	1	1
	21/8/50	1	6	72	2	3	10	17	2	-	-	14	6
		2	37	56	3	17	2	5	3	57	4	4	1
		3	54	27	3	19	-	2	3	72	-	1	-
D Grazing F.R.	5/8/47	1	54	44	5	10	1	-	-	-	-	3	1
		2	64	3	-	5	-	-	-	75	3	4	-
		3	68	5	1	5	-	-	-	74	1	2	1
	21/8/50	1	11	78	6	8	7	8	6	-	-	8	2
		2	73	-	3	5	-	-	1	62	-	3	-
		3	84	1	1	8	-	-	-	60	-	1	1

The vigorous sward which developed on all except the N.R. grass plots is reflected in the absence of "Bare Ground". Only in the N.R. grass plots, which were markedly more open in the bottom, did the value rise to 6 per cent. Throughout the table there is no marked inconsistency, and the main value of this form of analysis is to complement the yield data and herbage dissection analyses.

Seasonal changes in Growth and Botanical Composition

In Table VII is presented a summary of the seasonal production and botanical composition of Sub-treatments 2 N.R., 5 N.R., and 2 F.R. in the mowing series for the last two years of the trial. These treatments were chosen because they were reasonably representative,

because they show wide variations in botanical composition, and because they are of direct value in interpreting the chemical data presented in Part II.

In comparing the values in Table VII with those of the previous trials[2,3], it should be noted that there is a slight difference in the actual months chosen for seasonal groupings. This differance is due to a standardisation of the seasonal periods for all trials at this Division.

TABLE VII. ANNUAL AND SEASONAL YIELDS AND BOTANICAL CHANGES IN THREE SUB-TREATMENTS OF THE MOWING SERIES, FOR THE PERIOD SEPTEMBER 1948 - AUGUST 1950

Treatment	Season	Yield of Dry Matter lbs/acre	% of annual yields	Seasonal species composition % of D.M.			
				Ryegrass	Other Grasses	Red Clover	White Clover
A2	Spring*	3200	35	20	35	10	35
	Summer	2840	31	10	18	37	35
	Autumn	2470	27	7	32	26	35
	Winter	640	7	22	53	3	22
	Total	9150	100	13	30	23	34
A5	Spring	4020	34	29	26	3	42
	Summer	4020	34	10	15	6	69
	Autumn	2714	23	19	18	5	58
	Winter	1063	9	46	28	-	26
	Total	11817	100	22	21	4	53
B 2	Spring	6004	40	66	14	-	19
	Summer	4068	27	50	9	-	40
	Autumn	3464	23	45	11	-	43
	Winter	1501	10	68	14	-	18
	Total	15007	100	57	13	-	30

* September - November

The following notes cover the major points of interest in Table VII.

(i) The proportion of winter and spring growth is greater in the F.R. than in the N.R. series. This is due primarily to greater ryegrass growth, and secondarily to the greater growth of white clover as compared with red.

(ii) The proportion of autumn production is greatest in the unfertilised plots of the N.R. treatment, because of greater red clover growth.

(iii) It is important to note that, in the unfertilised N.R. plots, the ratio of white to red clover varies from 7 : 1 in winter to 1 : 1 in summer. In the two other sub-treatments shown in the table red clover is virtually absent.

(iv) Similar variations occur in composition of the grass component of Sub-treatment 2 N.R. The seasonal range in the proportion of ryegrass to total grasses was from 36 to 18 per cent.; the range in the corresponding fertilised plots (5 N.R.) was from 62 to 40 per cent.

Dry-matter Percentages

Dry-matter determinations were made in the routine of total yield estimations, and there were the usual complications due to variation in surface moisture, botanical composition, season of the year and physiological age of the individual leaves comprising the total herbage. Nevertheless, a close approximation can be obtained from the weighted averages of the several D.M. determinations made each year. Values calculated in this way from the records of the final year of the trial are presented in Table VIII.

TABLE VIII. PERCENTAGES OF DRY MATTER IN THE HERBAGE AS CUT FROM THE TREATMENTS. (Weighted averages for the final year of the trial: September 1949 - August 1950).

Treatment	Mowing No Return	Mowing Full Return	Grazing No Return	Grazing Full Return
Sub-treatment				
1	28.8	27.1	27.3	26.1
2	18.9	17.8	18.7	16.4
3	18.3	17.7	17.3	16.8
4	19.2	17.6	19.3	16.5
5	18.4	17.5	17.7	16.6
6	28.4	27.6	27.0	26.5

The outstanding point of interest is the large difference in water content between the cloverless plots and the grass-clover associations, the herbage from the former being harsh and fibrous in comparison with the latter. Within Sub-treatments 2, 3, 4 and 5, it is difficult to assess the significance of the range of D.M. percentages from 16.4 to 19.3 per cent. It is perhaps noteworthy that Sub-treatments 3 and 5 N.R. under both mowing and grazing are of slightly lower D.M. content than the less productive Sub-treatments 2 and 4. A similar trend is apparent when the F.R. series is compared with the N.R. series. If these differences are real, the natural conclusion would be that the increases in yield were generally achieved through greater growth of herbage of lower D.M. content.

GENERAL DISCUSSION

Comparisons with Other Trial Results

The artificial conditions under which the present trial was conducted make it desirable that comparisons be made with other trials more closely related to farming conditions. Only by such comparisons

can the validity of the conclusions drawn in the present paper be assessed in relation to full scale pasture management. The first trial where useful comparisons may be made is the grazing trial[1,2] in which the separate and combined effects of sheep dung and urine were measured under grazing conditions. The soil type was the same as in the present trial, virtually the same pasture species were used, and annual applications of superphosphate and lime were made. Comparisons may therefore be made with Treatment 5 N.R. and Treatment 5 F.R. under grazing.

The second trial which can be used for the same purpose consists of a one-acre block subdivided into ten paddocks, and sown in 1946 on land adjacent to the present trial. The block was seeded with the same mixture and has been under intensive rotational grazing with mature dry sheep at the same general defoliation levels. An annual application of 2 cwt superphosphate per acre has been made, and 1 ton of lime was applied during the first four years.

TABLE IX. HERBAGE YIELDS AND EFFECTS OF RETURN OF DUNG AND URINE IN COMPARABLE TRIALS

Trial	Main Treatment	Super cwt per acre per year	Average Annual Yield lb D.M. per acre	Relative Yields	Percentage of Total Dry Matter			
					Grass	White Clover	Red Clover	Other Species
Paddock grazing trial 1940-44	No Return	4	10,582	100	50	40	8	2
	Full Return	4	14,019	133	72	23	3	2
Plot trial 1946-50 Grazing series	No Return	8	9,293 *	100	44	49	7	-
	Full Return	8	11,309	121	56	40	2	2
Plot trial 1946-50 Mowing series	No Return	8	11,778	100	37	47	16	-
	Full Return	8	13,616	115	60	37	2	1
Mean yield of group of 10 paddocks 1946-50	Full Return	2	13,380	-	72	20	7	1

* Yield figures as shown are lower than actual totals by the unmeasured growth during the plot grazing periods.

In Table IX are presented the average annual yields and the contribution made by the major species to those yields.

The following points are of interest:

(i) The agreement between the yields of the two N.R. treatments and of the three F.R. treatments is good. The period covered is ten years and the data taken in conjunction with the annual yields from which they have been calculated reflect the evenness of the climatic conditions in this district.

(ii) Dung and urine cause considerable differences in percentage increases in yield. The large increase in the paddock grazing trial may have been due to phosphate limitation on the N.R. treatment, a point which was discussed in the final report of that trial[2].

(iii) In the N.R. series there is an interesting graduation in ryegrass performance from the mown plots through the grazed plots to the paddock grazing trial. Similarly, ryegrass contributes more in the paddock grazing trials where all dung and urine is normally returned than on the plots with full return. This agrees with the conclusions reached from consideration of the data in Table IV that mowing, as compared with grazing, depresses ryegrass and stimulates white clover.

(iv) Another reason for decreased ryegrass growth in the present trial may be found in the nitrogen losses which no doubt occurred during the collection period, especially in warm weather.

(v) Red clover which competed more strongly under lower fertility conditions (whether due to withholding dung and urine or superphosphate) and under mowing, tended to offset the increases in yield due to complete manurial additions.

(vi) Considered in conjunction with the results already presented, it is apparent that the effects of dung and urine on total pasture yields depend on both fertility levels and on the experimental technique. Thus, in the cloverless plots the increase due to dung and urine was 136 per cent. under mowing and 70 per cent. under grazing; in grass-clover plots with no superphosphate, the increase was 42 per cent. under both mowing and grazing; in the paddock grazing trial with 4 cwt superphosphate annually, the increase was 33 per cent.; while in the grass-clover plots with 8 cwt superphosphate annually, the increase was 21 per cent. under grazing and 15 per cent. under mowing. There could be no better illustration of the complexity of interactions between mowing, grazing, superphosphate application, and dung and urine.

The other field trials with which useful comparisons may be made are those of Johnstone-Wallace who showed, under entirely different climatic conditions, the ability of white clover to increase both the total yield and the yield of associated grasses. He found that *Poa pratensis* under mowing produced 900 lb D.M. per acre per annum, that white clover produced 3100 lb, and that a mixture of the two species produced nearly 5000 lb, of which 2200 lb was due to *Poa pratensis* and 2800 lb to white clover. There was, as in the present trial, a marked increase in the nitrogen level in the grass, together with much earlier grass growth in the spring.

Red Clover Growth

One of the most striking features of the trial was the difference in red clover vigour and longevity in the various treatments and sub-treatments. On this and similar areas, red clover seldom survives at high pasture production levels, for more than two years, a fact which is of considerable concern in trying to maintain a pasture with a good seasonal production balance. Disease is usually considered to be the main cause of red clover loss. It is therefore of particular interest that in this trial the red clover continued to grow well only in the Mowing N.R. Sub-treatments 2 and 4, where no superphosphate was applied, and where white clover was steadily decreasing. It is obvious that the factors of intensity and method of defoliation, treading, competition with clovers, and direct effects of fertiliser and of dung and urine, all need study in a consideration of the permanence of red clover in a mixed pasture.

General

The lack of response of cloverless pastures to superphosphate applications is of considerable practical importance. The absence of legumes on a large proportion of New Zealand's unploughable hill

country inevitably means that nitrogen is the limiting factor in growth. Topdressing with superphosphate under such conditions must be largely a waste of both labour and materials. Of equal importance is the lack of response to superphosphate on clover-grass plots of the F.R. series. On this particular soil type the even return of dung and urine from the mature animals used appeared to close the phosphate cycle through soil, pasture and grazing animal.

The rapidity with which the cloverless pastures decreased in yield to very low levels, even on a soil type which is classified as being of high inherent fertility, is also of practical interest. The pasture association which developed after two years is typical of those on large areas of land in this country. Again the conclusion is inescapable that improvement on such land can be achieved only through the clover plant.

It must be emphasised that the increase in total herbage yield due to the inclusion of clovers is the result not only of the growth of the clovers, but also of the better growth of the associated grasses. This is particularly noticeable in the plots receiving superphosphate, in which white clover yielded so well. Just how much of the better grass growth is due to nitrogen transfer from the clover plants, or to better moisture and temperature conditions resulting from the clover cover, or to other factors, cannot be directly estimated from this trial. However, the excellent climatic conditions and the lack of any marked drought leads to the conclusion that nitrogen transfer was the most important factor. The greater grass growth in the plots receiving superphosphate was probably due both to the direct benefit from the greater white clover growth, and to the secondary direct value to the grass plants from the applied superphosphate. It is to be expected that the demand of the grass plants for extra phosphate would increase, with the increase in soil nitrogen levels[12].

Considering further the superphosphate effects, there were indications from subsidiary plot trials that the responses recorded to this fertiliser were not due simply to its phosphate. In summer 1949, after some doubt had arisen about this matter, small sub-plots were laid down in Sub-treatments 2 and 4 of the mowing N.R. treatment. Calcium sulphate and monocalcium phosphate were applied singly and together, at rates equivalent to the superphosphate being applied to Sub-treatments 3 and 5. By the following spring, calcium sulphate had markedly increased the growth of white clover and produced a lighter green leaf-colour similar to that in Sub-treatments 3 and 5. No response was obtained from calcium phosphate alone but on the plots with phosphate and sulphate together, the growth of both white clover and grass later appeared to be more vigorous than on the plots with sulphate alone.

The conditions of the N.R. treatment were of course quite appropriate for the development of a sulphur shortage. In addition to the sulphur removed in the herbage without any return through the animal, sulphate leaching was probably high under the rainfall conditions, and with the virtual absence of local industrial activity, only a low sulphur intake from the air would be expected. It is also reasonable to expect that white clover with its shallower rooting system, would

feel the effects of a sulphur shortage earlier than red clover. There is also the possibility that white clover has a higher sulphur requirement than red clover.

Very little attention has been paid to plant sulphur requirements in New Zealand. Doak[29], however, recorded marked sulphur responses by lucerne. It has susually been assumed thaat adequate sulphur is normally applied in superphosphate, but rising costs, as well as the trend towards phosphatic fertiliser containing no sulphur, will no doubt focus attention on the separate nutrient requirements. To check the position on the soil conditions of this experiment a field trial has been laid down on an area adjoining the experimental site.

The seasonal spread of production in the highest yielding treatments (B2 in Table V) is of particular interest in comparison with the requirements of different types of stock under normal farming conditions. The approximate seasonal percentages of total feed requirement for a dairy cow calving on 1 August and producing 400 lb butterfat in 300 days are: spring, 38 per cent.; summer, 30 per cent.; autumn, 19 per cent.; and winter, 13 per cent. respectively[30]. Although the highest yielding treatment does not quite conform to such animal requirements, it is obvious that the adjustment in feed utilisation practices necessary to make the curves of feed supply and animal requirement coincide, decrease with the increasing pasture productivity. New Zealand's advantage in possessing a climate which permits of 10 per cent. of annual pasture production during the three winter months, is obviously a factor of major economic significance.

The tentative conclusion drawn from the results in Table VIII "that increases in yield are generally achieved through growth of herbage of lower D.M. content" is similar to the position found by Hudson[31], and has certain interesting implications. High total yields of herbage are of course one of the main aims in pastoral farming but it must be realised that their achievement may not be an unmixed blessing. Milking animals must ingest large quantities of dry matter for maintenance and high production, and a major limiting factor to intake is the high water content of rapidly growing herbage. Moreover the opinion is widely held[32] that animals derive considerable benefit from the ingestion of rough feed, which is commonly regarded as being particularly important in the prevention of metabolic disorders such as bloat.

The major conclusion to be drawn from the results presented in this paper is the number and complexity of the factors involved in the term "pasture production". No new principle of general applicability has emerged; what the author hopes to have achieved is a clearer appreciation of what is involved in the principles which have long been recognised.

Acknowledgements

The author gratefully acknowledges the assistance given by Messrs. Goodall, Ennis, Fitzgerald and Brougham in the field work, Misses Owen, Brown and Valentine in the herbage analyses, and Miss Oakley for the photographic reproductions. Thanks are also expressed to Mr. A. Glenday, Biometrician, for assistance with the statistical work.

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PASTURE GROWTH AND SOIL FERTILITY

II. THE INFLUENCE OF RED AND WHITE CLOVERS, SUPERPHOSPHATE, LIME, AND DUNG AND URINE ON THE CHEMICAL COMPOSITION OF PASTURE

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(Received for Publication, 24 July 1952)

Summary

(1) Analytical results for N, Ca, K, and P for the mowing series of the treatments described in Part I are presented for grasses, clovers and total herbage.

(2) Annual N levels in grass leaves varied from 2.2 per cent. (in the cloverless plots of the N.R. treatment) to 4.5 per cent. (in the grass-clover associations of the F.R. treatment). The corresponding annual yields of N in the herbage varied from 40 lb to 600 lb per acre. N levels in clovers were consistently higher than in the grasses growing in association.

(3) Ca levels in clovers were more than twice as high as in grass at all seasons, and neither species showed response to lime applications.

(4) K levels were consistently lower in clovers than in the grasses. Dung and urine caused marked increases in K levels in both clovers and grasses. K levels were much higher in grasses grown in association with clovers, than in the pure grass associations.

(5) P levels in grasses were slightly but consistently higher than in clovers. In the N.R. series superphosphate application caused a consistent increase in grass P levels with a smaller increase in clover levels. In the F.R. series there was no response in leaf levels to applied superphosphate.

(6) Seasonal changes in K concentrations were lower than in the other elements examined. N and P were high in winter and spring, and decreased in summer and autumn in both species. Ca. levels varied in the opposite direction.

INTRODUCTION

The analysis of pasture herbage for mineral elements has for the most part been directed to the determination of the adequacy of herbage as a source of the elements essential to animal health ,and to the provision of a quantitative or semi-quantitative means of assessing fertiliser requirement. Both are matters of great agricultural importance, and it is natural that the literature contains thousands of results of mineral analyses over a very wide range of species mixtures and environmental conditions. However, as Watson[1] has pointed out, many of these analyses are practically valueless for comparative purposes because they represent a single sample cut at some arbitary time during the growth period. Even where analyses have been performed at regular intervals[2,3,4,5], they almost invariably refer to the whole pasture herbage and not to the leaves of a single strain or species.

The previous paper in this series dealt with some of the individual factors which influence the productivity of pastures. The presence or absence of clovers, nutrient additions whether these be made artificially or through the dung and urine of grazing animals, the different defoliation actions of the mower and the grazing animal, and a number of other factors, all have marked effects on the yield and botanical composition of the pasture. Any one species will contribute quite differently to annual and seasonal herbage production according to the conditions which are imposed on it and each species has its own particular mineral requirements. It follows that an accurate assessment of mineral requirements can be obtained only through a knowledge of the requirements of at least each major species growing in the pasture association.

Information on individual species could be obtained only from certain treatments of the present trial. Dissections of pasture herbage were made into clovers and grasses with no further subdivision into the individual components of those groups. In all treatments where dung and urine were not applied, the "clovers" contained variable amounts of red and white clover, while the "grasses" were made up of ryegrass, cocksfoot, browntop and others. Only where dung and urine were returned did a simple association of ryegrass and white clover develop and did the dissections result in relatively pure samples of individual species.

As in a preliminary report on certain aspects of this investigation[6], the present paper deals with the leaf levels of nitrogen, calcium, potassium and phosphorus in the clovers, grasses and total herbage of the treatments described in Part I. The annual uptake of these elements from the soil is also presented. Seasonal changes in concentration are given only for one treatment which developed to a simple association of ryegrass and white clover.

Experimental Methods

The design of the experiment and the treatments imposed have been described in Part I. Samples for chemical analysis were drawn from the mowing series only. Just prior to each cut 20 rectangles each approximately 12 in. × 3 in., evenly distributed over each plot, were cut with handshears to mower height. The samples from duplicate plots were combined and the herbage separated into grasses and clovers, weeds being discarded. The grass and clover samples were dried, ground, and at the end of each three-month period were bulked in proportion to D.M. yields.

Duplicate analyses were made using the methods described by Sears and Newbold[4].

Results and Discussion

In Table I are shown the summarised results of 3-monthly bulkings calculated for annual periods. These are presented as percentages of the four elements, nitrogen, calcium, phosphorus, and

TABLE I. CHEMICAL COMPOSITION AND YIELD OF ELEMENTS IN THE HERBAGE FROM THE MOWING SERIES

Sub-Treatment	Period of Growth	Grasses + Clovers								Clovers								Grasses							
		% of Dry Matter				Total Elements lb. per acre				% of Dry Matter				Total Elements lb. per acre				% of Dry Matter				Total Elements lb. per acre			
		N	Ca	K	P	N	Ca	K	P	N	Ca	K	P	N	Ca	K	P	N	Ca	K	P	N	Ca	K	P
A. NO RETURN OF DUNG AND URINE																									
1	1946 - 47	2.27	0.64	2.48	0.46	62	17	68	13	-	-	-	-	-	-	-	-	2.27	0.64	2.48	0.46	62	17	68	13
	1947 - 48	2.19	0.71	2.17	0.45	37	12	37	7	-	-	-	-	-	-	-	-	2.19	0.71	2.17	0.45	37	12	37	7
	1948 - 49	2.51	0.61	2.17	0.45	50	12	43	9	-	-	-	-	-	-	-	-	2.51	0.61	2.17	0.45	50	12	43	9
2	1946 - 47	4.32	1.16	3.26	0.40	467	123	355	43	4.74	1.39	3.27	0.38	362	106	250	29	3.31	0.53	3.31	0.44	105	17	105	14
	1947 - 48	4.40	1.08	2.80	0.39	429	105	274	38	4.75	1.34	2.56	0.40	323	91	174	27	3.56	0.47	3.36	0.37	106	14	100	11
	1948 - 49	4.11	1.01	3.12	0.45	395	97	299	43	4.75	1.55	2.92	0.41	233	76	143	20	3.42	0.44	3.30	0.49	162	21	156	23
3	1946 - 47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1947 - 48	4.51	1.14	2.78	0.46	502	127	309	51	4.81	1.43	2.40	0.42	374	111	187	33	3.92	0.49	3.42	0.55	128	16	112	18
	1948 - 49	4.40	1.08	3.12	0.50	529	129	375	60	4.90	1.54	2.71	0.44	334	105	185	30	3.74	0.46	3.65	0.57	195	24	190	30
4	1946 - 47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1947 - 48	4.45	1.20	2.87	0.44	482	130	311	48	4.72	1.43	2.63	0.40	378	115	211	32	3.65	0.53	3.51	0.56	104	15	100	16
	1948 - 49	4.14	1.03	3.19	0.44	417	112	322	44	4.72	1.51	3.04	0.41	288	92	186	25	3.23	0.50	3.41	0.48	129	20	136	19
5	1946 - 47	4.39	1.16	3.36	0.43	522	138	399	51	4.77	1.40	3.31	0.40	412	121	286	35	3.38	0.53	3.48	0.49	110	17	113	16
	1947 - 48	4.56	1.20	2.72	0.48	523	138	312	55	4.95	1.53	2.26	0.42	387	120	177	33	3.69	0.49	3.66	0.59	136	18	135	22
	1948 - 49	4.38	1.09	3.23	0.51	534	133	394	61	4.99	1.53	2.93	0.45	346	106	203	31	3.57	0.51	3.63	0.57	188	27	191	30
6	1946 - 47	2.27	0.65	2.32	0.47	57	16	59	16	-	-	-	-	-	-	-	-	2.27	0.65	2.32	0.47	57	16	59	16
	1947 - 48	2.31	0.61	2.30	0.49	41	11	41	9	-	-	-	-	-	-	-	-	2.31	0.61	2.30	0.49	41	11	41	9
	1948 - 49	2.34	0.62	2.14	0.47	51	14	47	10	-	-	-	-	-	-	-	-	2.34	0.62	2.14	0.47	51	14	47	10

TABLE I (Continued)

B. FULL RETURN OF DUNG AND URINE																								
1	1946 - 47	2.46	0.63	2.80	0.47	107	27	122	21	-	-	-	-	-	-	-	-	2.46	0.63	2.80	0.47	107	27	122	21
	1947 - 48	3.07	0.63	2.90	0.51	134	28	127	22	-	-	-	-	-	-	-	-	3.07	0.63	2.90	0.51	134	28	127	22
	1948 - 49	2.99	0.59	2.90	0.51	173	34	167	29	-	-	-	-	-	-	-	-	2.99	0.59	2.90	0.51	173	34	167	29
2	1946 - 47	3.90	0.94	3.74	0.49	460	110	443	57	4.74	1.40	3.59	0.41	230	68	174	20	3.30	0.60	3.85	0.53	230	42	269	37
	1947 - 48	4.51	0.91	3.72	0.49	618	125	511	66	4.90	1.32	3.33	0.43	338	91	230	30	4.10	0.50	4.12	0.53	280	34	281	36
	1948 - 49	4.32	0.74	3.86	0.49	665	114	596	75	5.06	1.34	3.52	0.45	226	60	157	20	4.00	0.49	4.10	0.50	439	54	439	55
3	1946 - 47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1947 - 48	4.58	0.93	3.69	0.49	608	123	490	65	4.90	1.38	3.28	0.44	320	90	214	29	4.25	0.49	4.07	0.53	288	33	276	36
	1948 - 49	4.29	0.79	3.85	0.52	649	119	584	80	5.04	1.45	3.49	0.47	225	65	156	21	3.96	0.50	4.00	0.55	424	54	428	59
4	1946 - 47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1947 - 48	4.51	0.94	3.57	0.48	579	120	459	62	4.83	1.38	3.18	0.41	315	90	207	27	4.48	0.47	3.98	0.55	284	30	252	35
	1948 - 49	4.41	0.84	3.85	0.49	668	126	583	73	5.05	1.43	3.39	0.43	275	78	185	23	4.05	0.49	4.10	0.51	393	48	398	50
5	1946 - 47	4.02	0.94	3.60	0.46	484	113	433	56	4.97	1.43	3.38	0.43	230	66	156	20	3.41	0.63	3.72	0.48	254	47	277	36
	1947 - 48	4.48	0.94	3.59	0.49	588	123	473	64	4.90	1.35	3.19	0.46	312	86	203	29	4.06	0.54	3.97	0.51	276	37	270	35
	1948 - 49	4.38	0.86	3.76	0.51	650	127	558	76	5.01	1.46	3.40	0.48	271	79	184	26	4.02	0.51	3.97	0.53	379	48	374	50
6	1946 - 47	2.50	0.69	2.79	0.49	118	32	132	23	-	-	-	-	-	-	-	-	2.50	0.69	2.79	0.49	118	132	32	23
	1947 - 48	3.06	0.67	2.95	0.56	127	28	123	24	-	-	-	-	-	-	-	-	3.06	0.67	2.95	0.56	127	28	123	24
	1948 - 49	3.06	0.66	2.88	0.56	177	39	167	33	-	-	-	-	-	-	-	-	3.06	0.66	2.88	0.56	177	39	167	33

potassium, in the dry matter of grasses, clovers and total herbage (calculated from the yield and composition of the separate components). For each element, 236 analyses were made during the course of the trial but in order to keep tabulated data within reasonable limits these have been summarised into the 52 annual percentage figures shown. The table contains in addition, under the heading "Total Elements", the weight of each element in the herbage produced annually by all plots, calculated on a per acre basis. These values were calculated from the yield data given in Part I and from the concentrations of the elements in the herbage.

The results in Table I are discussed below in terms of the individual elements:

Nitrogen: In the cloverless sub-treatments the average N content of grasses was 2.31 per cent. in the N.R. and 2.36 per cent. in the F.R. treatment. Browntop was dominant in these plots, whereas ryegrass assumed this position in the grass-clover associations.

The average N content of clovers in the grass-clover combinations of the N.R. treatment was 4.81 per cent., and of grasses, 3.49 per cent.; in the F.R. treatment the corresponding N values were 4.95 per cent. for clovers, and 3.86 per cent. for grasses. The N.R. clovers consisted of varying proportions of white and red; the N.R. grasses were dominantly ryegrass with substantial proportions of browntop and cocksfoot in Sub-treatments 2 and 4. The F.R. clovers were virtually all white, and the grasses virtually all ryegrass.

It has been shown in Part I that superphosphate increased the yield and the proportions of ryegrass and white clover in the grass-clover associations of the N.R. treatment. Increases in N level of both clover (from 4.74 to 4.92 per cent.) and grasses (from 3.45 to 3.71 per cent.) also resulted from superphosphate application. The total N yield therefore increased markedly. There was no change in the corresponding F.R. sub-treatments due to superphosphate.

In Sub-treatments 2-5, the N levels in the total herbage in both treatments were similar. The extra clover content of the pasture in the N.R. treatment balanced the higher N level in the grass in the F.R. treatment. The total herbage of both treatments thus had an average crude protein content of about 27 per cent. The most striking difference between the N.R. and F.R. treatments was the increase in N yields of the grasses in the latter due both to increase in N level and a marked increase in the grass-to-clover ratio.

A comparison of Sub-treatments 5 and 6 N.R. for the period September 1946-August 1949 shows that nitrogen supplied to the soil by clover increased the N yield of the associated grasses nearly threefold. This resulted from increases both in yield (1.89 : 1) and in N level (3.53 : 2.29) of the grass herbage. The increase due to clovers was similar on the F.R. treatment where there was the additional transfer of N above ground by the animal. The increase resulted both from the increased yield of grass (1.62 : 1) and from the higher N levels in the grass herbage (3.81 : 2.87).

Calcium: It has been shown repeatedly that calcium levels are markedly higher in clovers than in grasses. In this trial the average

Ca values were 1.48 per cent. for clovers and 0.48 per cent. for grasses in the grass-clover combinations of the N.R. treatment. The corresponding values in the F.R. treatment were 1.39 and 0.50 per cent.

No response to lime as measured by Ca level of the herbage was obtained in the grass-clover mixtures. Hence, in any sub-treatment the Ca yields of the mixed herbage depended on the ratio of clover to grass and on total herbage yield.

In the cloverless sub-treatments, average calcium levels were markedly higher (0.65 per cent.) than in the grass of the grass-clover combinations (0.49 per cent.). There is no evidence to show whether this is due to the more complex association in the former or to other causes associated with poorer growth of all species.

Potassium: Clovers in both treatments were lower in potassium content than were the grasses growing in association with them. In the F.R. treatment the grasses contained 4.0 per cent. K and the clovers 3.3 per cent. In the N.R. treatment where the botanical composition was more complex the levels were 3.5 and 2.7 per cent. respectively. The consistently higher content of K in the former treatment is probably a direct result of the high concentrations of this element in urine[4]. K levels were higher in the grasses growing in association with clovers, than in the pure grass associations, the mean figure for Sub-treatments 5 being 3.74 per cent., and for Sub-treatments 6, 2.56 per cent.

Phosphorus: The P content of the grasses was consistently higher than that of the clovers growing in association with them. In both treatments the value was 0.53 per cent. for the grasses; in the N.R. treatment the clovers contained 0.42 per cent. and in the F.R. treatment, 0.44 per cent.

In the N.R. treatment the addition of superphosphate caused an increase in the grass P levels and a slight increase in clover P levels. Combined with the greater herbage yields obtained with superphosphate this led to substantially higher P yields in the total herbage.

In the F.R. treatment neither yield nor P level in the herbage was increased through superphosphate application. It would appear that under the conditions of this trial the return of dung and urine from mature dry sheep closed the phosphate cycle through soil, plant, and animal. This conclusion is strengthened by comparing Sub-treatments 3 and 5 N.R. with 2 and 4 F.R. Phosphorus levels in the former pair which received heavy superphosphate applications are certainly not higher than those of the latter which received none.

It has already been shown that on the basis of yield and botanical composition the sub-treatments may conveniently be divided into five distinct groups: 1 and 6 N.R.; 1 and 6 F.R.; 2 and 4 N.R.; 3 and 5 N.R.; and 2, 3, 4 and 5 F.R. Table I demonstrates that these groups also hold for chemical composition. In Table II are summarised for the period 1948-9 the average D.M. yields, concentrations of the four elements and yields of elements in the herbage for these five groups.

TABLE II

Average D.M. yields and concentrations of the four elements, of the main sub-treatment groupings for the period September 1948-August 1949

Group	D.M. Yield (lb/ac)	N		Ca		K		P	
		%	Yield (lb/ac)	%	Yield (lb/ac)	%	Yield (lb/ac)	%	Yield (lb/ac)
(a) 1 and 6 N.R.	2200	2.4	50	0.6	13	2.2	45	0.46	10
(b) 1 and 6 F.R.	5900	3.0	180	0.6	36	2.9	170	0.54	30
(c) 2 and 4 N.R.	9900	4.1	410	1.0	100	3.2	310	0.45	45
(d) 3 and 5 N.R.	12100	4.4	530	1.1	130	3.2	380	0.50	60
(e) 2, 3, 4, 5 F.R.	15200	4.4	660	0.8	120	3.8	580	0.50	75

The table brings out very clearly the large differences in nitrogen and mineral uptake from the soil by pastures at different production levels and of different botanical compositions. The treatments composed have led to differentials of up to approximately 10:1 in all elements other than phosphorus where they are up to 7.5:1.

The value of the clover plant in raising the yield of pasture herbage has already been emphasised and the nitrogen values in Table II give quantitative expression to the major factor in this increase. A visual demonstration that nitrogen was the primary limiting factor in the cloverless pastures is given in Fig. 2, where the response to nitrogen on cloverless plots is particularly marked.

Seasonal Variations in Chemical Composition

The preliminary report of seasonal changes in chemical composition of grasses and clovers in this trial[6] did not treat fully the difficulties of interpretation caused by complexity in botanical composition and by differences in height at cutting. It is considered that, in view of the values already published, the purpose of the present paper can best be served by presentation of the seasonal analyses for the 2-year period from spring 1947 to winter 1949 of the herbage of Sub-treatment 2 F.R. The reasons for this choice are: (a) the general botanical stability within this plot after the autumn of 1947; the "grasses" were nearly all ryegrass and the "clovers" were all white clover; (b) the lack of response to lime or superphosphate within the F.R. treatment and the consequent conclusion that the growth on Sub-treatment 2 is typical of a sward of ryegrass and white clover growing under first-class soil fertility conditions; (c) the mowing times which were usually determined by the height of the grass-clover plots of the F.R. treatment. The seasonal trends were therefore essentially those which would be expected in herbage cut at the 4-6 in. stage of growth, i.e., herbage such as would be eaten by animals in normal rotational grazing management.

The seasonal analyses for N, Ca, K and P are given in Fig. 2, the separate figures for grass, clover and total herbage (calculated from individual values) being shown. Considered in terms of the individual elements the following are the important points:

Nitrogen: At all seasons leaf levels of nitrogen were higher in clover than in grass, the only time of the year when the grass approached the clover in nitrogen content being the winter period of 1948. Apart from this there was a fairly uniform pattern, with a definite drop in both species during summer, and with the highest levels occurring in winter.

Calcium: Calcium levels were markedly higher in clovers than in grasses with both species showing a parallel rise and fall through the seasons. Peaks occurred in both summer periods, these being maintained into the autumn of 1948 but dropping in the autumn of 1949. Low calcium levels occur in both species during winter and spring.

Phosphorus: The phosphorus level in grass was slightly but consistently higher in grass than in clover, with the greatest difference occurring in the summer periods of both years. In general there is a strong inverse relationship with calcium, the peaks of phosphorus content being in the winter and spring, with the low points consistently in the summer and autumn periods.

Potassium: In all seasons leaf levels for grasses were higher than those for clovers. Changes due to season are lower than for the other three elements.

The most important conclusion is that changes in chemical composition of the herbage throughout the year are the result both of the ratio of grass to clover, and of the seasonal changes in leaf levels. Thus white clover content rises from 18 per cent. of the herbage in winter to 40 per cent. in summer, when calcium levels of total herbage are determined largely by this species.

General Discussion

For reasons already outlined in Part I it is important to compare the results already presented with those of the previous paddock grazing trial[4,5]. As in comparisons of yield and botanical composition, the levels of the four elements in Sub-treatments 5 N.R. and 5 F.R. may be compared with those of the "no return" and "full return" paddocks of the grazing trial. The similarity is marked. Where dung and urine were not returned, the levels of N, Ca, K and P in the total herbage in the present trial were 4.4, 1.0, 3.2 and 0.5 per cent., compared with 4.4, 1.0, 2.8 and 0.46 per cent. for the previous trial. Where dung and urine were returned, the levels were 4.4, 0.8, 3.9 and 0.52 per cent. for the present trial and 4.5, 0.8, 3.4 and 0.46 per cent. for the previous one.

The only differences between the two trials lie in the levels of P and K which were higher in both treatments of the present plot trial. The significance of these differences cannot be assessed from the available data, but if they are real they cannot be explained on botanical grounds. The higher grass-to-clover ratio of the paddock grazing trial should have resulted in higher levels of both elements. The high potassium levels in the present trial do, however, lend support to the assumption that this element did not limit growth in the N.R. plots, which were subject to high losses through the herbage.

A comparison of the results reported here with those obtained by Hudson, Doak and McPherson[2] under similar climatic conditions but on a very different soil type show similar levels for the four elements in the total herbage at production levels between 5000 lb and 11000 lb D.M. per acre per annum. Superphosphate responses as measured by herbage levels in the late winter and early spring were however much more apparent, and maximum P concentrations of 0.93 per cent. were observed. Seasonal fluctuations in leaf levels of all elements followed essentially the same trends.

Rigg and Askew[3,9] investigated the yield and chemical composition of various Nelson pastures where both soils and climatic conditions were different from those at Palmerston North. Yields were comparatively low and the botanical composition was complex, but levels of all four elements were similar to those reported here.

Fig. 1. View from north end of the mowing series (see Fig. 1 in Part I of this series) showing responses to added nitrogen. The pathway shown was separated from the plot areas down the junction line of the plots, during the last year of the trial. The response to urea (3 cwt per acre) on this pathway, was very marked except on the areas previously in the grass-clover F.R. plots. The responses to superphosphate on the grass-clover N.R. plots are also visible, as is the lack of response on the cloverless N.R. plots in the foreground.

The conclusions of Greenhill and Page[10] that there exists a strong correlation between N and P levels of mixed pasture herbage is borne out by the present results on seasonal variations (Fig. 1). The danger of applying this generalisation too widely is however clearly demonstrated in the cloverless pastures in both treatments. Although P levels are relatively high in comparison with the grass-clover associations, the N levels are little more than half those of the latter.

As has already been mentioned, very few investigators have considered the concentrations of nitrogen and mineral elements either

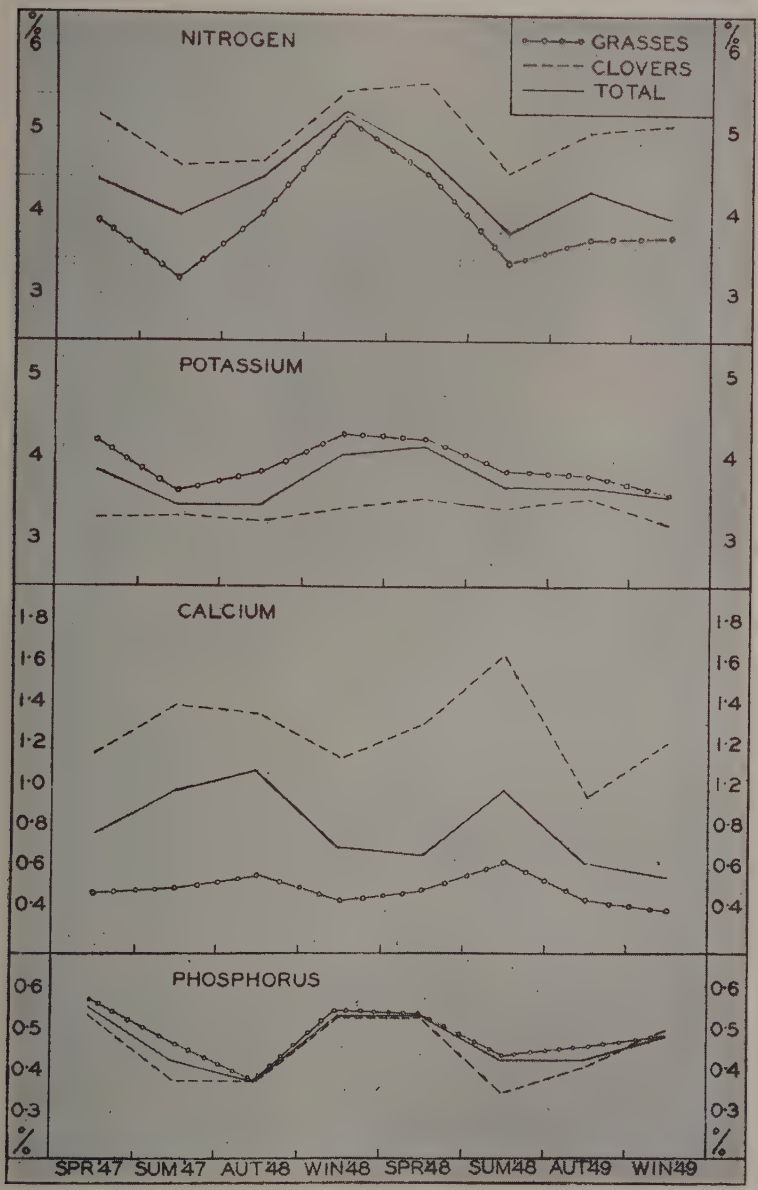

Fig. 2. Seasonal variations in the N, K, Ca and P leaf levels of the herbage in Sub-treatment 2 F.R. of the mowing series. Levels shown are percentages of Dry Matter.

in the individual species comprising the pasture association or in the grasses and clovers as groups. Fagan and co-workers[7] dissected a temporary Italian-ryegrass - Montgomery-red-clover pasture into its constituent species and analysed these separately at weekly intervals over a 25-week period. Despite the difference in species, the results for N, Ca and P are similar to those in the present report both with regard to leaf levels and to seasonal variations. The weekly analyses however reveal short term differences in concentrations which were not apparent from the 3-monthly analyses on which Table I is based.

A more recent publication by Stewart and Bear[8] applied the same techniques to a cocksfoot – Ladino-clover pasture. Their paper is particularly valuable because of the very full ash analyses which include non-essential as well as essential micro- and macro-elements. P and K were consistently higher in cocksfoot than in clover, while the position was reversed for calcium and nitrogen.

In addition to the apparent discrepancy in phosphate levels between this trial and the previous paddock grazing trial already mentioned there are other anomalies in the phosphate situation. For example, in Sub-treatment 2 N.R. where all herbage was discarded and no phosphate applied, the yield of phosphorus in the herbage over the 5½-year trial period, represented a loss from the soil of about 200 lb P, equivalent to about 1 ton superphosphate per acre. Despite this depletion of soil phosphate, clover phosphorus levels were only slightly lower than in those plots receiving heavy superphosphate applications, and there was no tendency towards decreasing phosphorus levels in either clover or grass as the trial progressed. On the other hand, total yields steadily decreased, and the proportion of red to white clover approached unity largely because of marked decrease in white clover content. It must therefore be natural to conclude that soil phosphate levels were adequate on all sub-treatments during the course of the trial and that some nutrient element in superphosphate other than phosphorus was limiting growth in the Sub-treatment 2 N.R. Small scale experiments on Sub-treatments 2 and 4 N.R., as reported in Part 1, suggest that sulphur is implicated. If these tentative conclusions prove to be correct it may well be that the effect of dung and urine, under the conditions of climate, soil and production level described here, is more important in closing the sulphur cycle than in closing the phosphorus cycle through soil plant and animal.

Both Hudson *et al*[2] and Rigg and Askew[3] consider the seasonal variation in the calcium-phosphorus ratio in relation to animal nutrition. The results in Fig. II show that when phosphorus concentration was low (summer and autumn), calcium concentrations were at a maximum and *vice versa*. This in turn resulted in marked differences in the Ca : P ratio, which was 2.2 : 1 in summer and autumn, and 1.4 : 1 in winter and spring. The differences are the result both of changing levels in the leaves of both grasses and clovers with season, and of the high clover content of the pasture in summer and autumn. The values quoted are the results of 3-monthly bulkings of individual cuts; had analyses been made of the individual cuts the differences would undoubtedly have been much greater at certain critical periods. This is particularly well demonstrated in the data of Hudson *et al*[2].

Acknowledgements

The authors wish to acknowledge the assistance given by Miss Owen with the herbage separations, and by Mr. Turner and Miss King with the chemical analyses.

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PASTURE GROWTH AND SOIL FERTILITY

III. THE INFLUENCE OF RED AND WHITE CLOVERS, SUPERPHOSPHATE, LIME, AND DUNG AND URINE ON SOIL COMPOSITION, AND ON EARTHWORM AND GRASS-GRUB POPULATIONS

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(Received for Publication, 16 October 1952)

Summary

(1) Analytical results for organic matter, N, P, and exchangable Ca, Mg, and K, in the top 2 in. of soil, and estimates of total earthworm and grass-grub *(Odontria* spp.) populations, are presented for the mown plots described in Part I of this series.

(2) Soil organic matter and nitrogen were increased by clovers, and very markedly by the return of dung and urine.

(3) The application of superphosphate increased the available P of the soil in all cases. Lime when applied in addition to superphosphate increased the available P, but applied alone had no such effect. The return of dung and urine kept the soil P at much higher levels than in the N.R. series.

(4) The percentage base saturation depended on the balance between the cations removed in the herbage, and the amounts returned in the dung and urine, lime and superphosphate. In general, the Ca and K levels were high, and Mg levels were low.

(5) The percentage of water-stable aggregates was high in the cloverless pastures of the N.R. and F.R. series; in the grass-clover N.R. sub-treatments the percentage aggregation was lower, but in the grass-clover F.R. sub-treatments it was the highest recorded. Aggregation was highest at the 4-6 in. levels in all sub-treatments.

(6) The weight of earthworms was positively correlated with pasture production and approximated that of the stock which could be carried on the pasture. The main earthworms species were *Allolobophora caliginosa* and *Lumbricus rubellus.*

(7) There was a similar relationship between numbers of grass-grub larvae and pasture production.

Introduction

Parts I and II of this series reported the effects of clover, superphosphate, lime, and grazing and manuring by sheep, on pasture yields, and on botanical and chemical composition. The experiment was designed primarily as a study of the effects of pasture management on the yield and composition of herbage; but in the later stages of the trial the soil was also examined and some large differences were disclosed. There is evidence that these differences were induced by the treatments applied during the trial, and it is considered that they indicate the nature and extent of changes in soil fertility which can be induced by management of pastures under the climatic conditions prevailing in much of the North Island of New Zealand. The authors therefore consider that publication of the soil data is justified.

There are several recent reviews available of the effects of pastures on soil fertility. Jacks[1] emphasised the part played in soil structure improvement by the roots of pasture plants (especially the grasses), and the beneficial effect of legumes on soil-nitrogen levels. He also stressed the limited time during which soil improvement developed through pastures lasts under cultivation.

As a generalisation he concluded that the full soil improvement effect of a good pasture is achieved in two years in moist, and in four years in dry temperate regions, and that the soil structure so formed may be destroyed by cultivation in about the same periods.

Russell[2], treating the subject in more detail, quotes many examples of soil structure improvement, and of soil nitrogen increase through pastures, and of the leaching and gaseous losses continually occurring from the soil. The obvious conclusion to be drawn is that soil fertility is continually changing and depends at any time on the interaction of soil type, climate, fertilisers, and the plants and grazing animals in use. This view is emphasised by both Crowther[3] and Davies[4] in recent review papers.

Experimental data on the effects of different pastures and rotations on the soil have recently been published by several workers. Woodruffe[5] and Penman[6] both recorded marked improvement in soil structure and fertility, after the use of subterranean clover in Australian cereal cropping rotations. Karraker[7] in Kentucky reported a much greater soil nitrogen increase from red clover pasture than from a pasture of cocksfoot with a small amount of volunteer clover. In lysimeter trials with cropped species he recorded[8] over an 11-year period, an increase in soil nitrogen of 329 lb per acre under white clover, a static position under pure Kentucky bluegrass *(Poa pratensis)*, and a loss of 730 lb N per acre from soil kept free of vegetation.

In New Zealand a number of reports deal with changes in available Ca, P, K and other nutrient elements in soils under pastures of different botanical composition and under different management and fertiliser treatments[9,10]. Doak[11] recorded marked progressive increases in soil nitrogen during the life of grazed high production pasture. More recently the same worker has measured[12] the losses of nitrogen occurring from urine voided during grazing. There have been no trials, however, where the effects of pastures of widely different productivity on soil fertility have been examined, nor has there been any investigation of the period over which fertility induced by pasture is dissipated under cropping.

Earthworm studies were included in the present investigation in order to obtain further information on the ability of different pastures to maintain high worm populations. Russell[2] presents an excellent summary of the literature on the occurrence and activity of earthworms in soils under different vegetation and management. He lists as their major attributes: the digestion and incorporation of waste material into the soil; the better aeration, greater extension of plant root-range, and increased water penetration through the earthworm burrows; and the possible direct improvement in soil structure due to worm casts. On this last point he quotes evidence to show that worm-casts have a better structure if produced on pasture than on arable

land. Russell's general conclusion was, however, that the improvement in soil structure due to the pasture itself is very much greater than that due to associated earthworm activity.

The earthworm populations depend on soil moisture, temperature, pH, and the calcium and organic material available as food. Evans' data[18] from Rothamstead showed per acre populations of 0.3 to 0.8 million (700 lb live-weight) under old pastures, 0.3 million (600 lb) under leys, and 0.2 million (120 lb) after five years as arable land following old pasture. Guild[14] recorded earthworm populations ranging from 0.05 million per acre under Scottish unimproved hill pastures, up to over 0.3 million per acre under fertile 4-year sown lowland pastures.

In Maryland, Slater and Hopp[15] reported large differences in earthworm populations in soil under pasture and under crops. Soil under continuous pasture (which also gave some winter protection) contained 960 lb live worms per acre, but soil under continuous maize cropping contained 77 lb per acre. Large differences, in favour of the soil under pasture, occurred in the amounts of water-stable aggregates, and in the soil pore-spaces.

New Zealand studies include the preliminary results from worm feeding trials at this Station reported by Waters[16], and the field survey work and the pot studies by Nielsen[17]. Both these workers found that adequate organic material and Ca are necessary to sustain high earthworm populations. Nielsen also reported evidence that earthworms excrete substances advantageous to ryegrass growth.

The grass-grub *(Odontria* spp.) is a serious pest in New Zealand. The main damage is that which is caused to pastures by the larvae as they develop in the soil and feed on grass and clover roots, but adult beetles also feed on cruciferous crops, fruit, shrub, and ornamental plants. Kelsey[18] has recently given a review of the life cycle, estimates of the damage caused, and also of methods for control in the field.

An important point emphasised by Kelsey is that, because the female beetle lays some of its eggs before flying there is the liability for a continuing increase in grass-grub populations within any paddock. He showed the upper limits of grass-grub populations to be dependent on the amounts of pasture roots available as food, but there is also a considerable control at the upper population levels due to the cannibalistic practices of the larvae.

Kelsey[19] has found larval populations of up to 0.9 million per acre in good unirrigated Canterbury pastures, and up to 3.5 million per acre in first-class irrigated Canterbury pastures. In the North Island he found populations of approximately 0.3 million per acre under pastures classified by him as "poor", approximately 1.2 million per acre under "fair" pastures and on a single "good" pasture count he found nearly 2.0 million per acre. As would be expected in a field survey, however, there was considerable variation, and also the classification of pasture productivity by eye is always subject to error.

The data reported in this paper were obtained as a supplement to Kelsey's field estimates.

Experimental Methods

The design of the experiment and the treatments imposed have been described in Part I of this series. Samples for soil analysis and for estimation of earthworm and grass-grub populations were drawn from the mowing series only. The soil analyses presented in this paper are a selection from soil analyses made by B. R. Watkin[20], together with a complete set of analyses made at the end of the main pasture trial (December, 1950). The earthworm counts presented were those made in the early spring as at this time of the year earthworm populations appear to be a maximum in this area[20,21]. The grass-grub populations were estimated from a single sampling in the early winter of 1951.

For the soil analyses, 20 cores, 0-2 in. depth, were taken at random from each plot with a ½ in. diameter sampler. Previous sampling checks[20] had shown this number of cores to give an adequate sample from each plot. The analyses were made in duplicate on the bulked samples from each plot.

Organic matter was determined by loss on ignition, total N by the usual Kjeldahl method and available phosphorus by a modification of the Egner method[20]. Determinations of soil pH were carried out potentiometrically on a 1: 2½, soil-water suspension after thirty seconds, and the exchangeable bases were measured in an ammonium acetate extract, calcium as oxalate, magnesium as hydroxyquinolate (Metson[22]) and potassium as cobaltinitrite (Piper[23]). Soil aggregation determinations were made by Watkin in 1948 on samples at depths down to 9 in., using a modification of the wet sieving method of Bouyoucos[24]. For the earthworm and grass-grub counts, two turves each 1 ft square and 6 in. deep, were dug out with a spade from each plot. The soil below the extracted turves was then examined to a depth of well over one foot and the few worms or grass-grubs found were added to those found in the turves. The separated worms were allowed to scour in fresh water for a day before drying on blotting paper and weighing.

Results and Discussion

The mean soil analytical results from the duplicate plots of each treatment are shown in Table I. All results are from the sampling

TABLE I. CHEMICAL ANALYSIS OF THE TOP 2" OF SOIL FROM THE MOWING SERIES

Treatment	Organic Matter (%)	Nitrogen (%)	C/N ratio	Available phosphorus (lb/ac P_2O_5)	Base exchange capacity (m.e.%)	Base Saturation (%)	pH	Exchangeable bases		
								Ca (m.e.%)	Mg (m.e.%)	K (m.e.%)
No Return										
Sub-treatment										
1	8.3	0.26	18.7	46	20.7	63.3	6.2	11.0	1.37	0.61
2	8.6	0.30	16.5	12	21.2	56.1	6.0	9.8	1.27	0.61
3	8.5	0.30	16.4	32	22.0	57.3	5.8	11.6	1.02	0.37
4	8.7	0.30	16.8	16	21.9	77.6	6.4	14.8	1.31	0.47
5	9.3	0.31	17.4	76	21.2	83.0	6.5	16.3	0.97	0.36
6	8.3	0.26	18.4	112	20.7	85.0	6.5	16.5	0.97	0.51
Full Return										
Sub-treatment										
1	9.6	0.32	17.4	96	20.5	82.9	6.5	12.5	1.14	1.43
2	9.8	0.38	15.1	75	21.6	81.5	6.2	14.1	1.53	2.12
3	9.8	0.38	14.8	121	22.9	85.6	6.1	15.6	1.39	1.85
4	9.9	0.38	14.9	75	22.3	97.7	6.6	17.4	1.36	2.04
5	9.7	0.38	14.6	133	22.6	98.1	6.6	18.6	1.14	1.93
6	9.5	0.31	17.6	167	22.1	100	6.9	17.9	1.22	0.97

in December, 1950, except for the P data which are the means of three determinations made by Watkin between January and October, 1948. There are several points of interest clearly visible in the data:

Organic Matter

The return of dung and urine was the major factor in increasing soil organic matter, although the presence of clovers produced a consistent though small increase.

Nitrogen

Reference to the herbage composition data in Part II shows that whereas the leaf nitrogen levels of the grasses closely reflect the soil nitrogen levels, leaf levels in clovers show no such relation.

The calculated C/N ratios are all high, probably because of the rather high C values calculated from the loss on ignition. The ratios are, however, consistently high in the cloverless plots, lower in the presence of clovers, and still lower where the dung and urine were also returned.

No partition of the soil nitrogen was made on these samples, but it had been found[20] in 1948 that nitrate nitrogen was very much higher in Sub-treatments 2-5 F.R. than in all others; the sum of the nitrate and ammonia fractions was 3.6 per cent. of the total soil N in Sub-treatments 2-5 F.R., 1.4 per cent. in Sub-treatments 2-5 N.R., 1.3 per cent. in Sub-treatments 1 and 6 F.R., and 1.2 per cent. in Sub-treatments 1 and 6 N.R.

Phosphorus

The most striking result shown is the much lower amount of available P in the soil of the grass-clover sub-treatments. It was shown in Part II that the greatest uptake of P occurred in the grass-clover sub-treatments. In the N.R. series the lower soil P levels of the grass-clover sub-treatments could therefore be explained as due to this greater uptake by the herbage. In the F.R. series, however, the reasons are not so obvious for the lower available P in the upper soil layer of the grass-clover than of the cloverless plots.

There are probably many possible explanations; among these are: (1) the dung and urine returned to Sub-treatments 1 and 6 may have contained more available P than would have occurred had the collection been made from the individual sub-treatments, each grazed separately; (2) the high earthworm populations of the grass-clover plots probably transferred more of the soil, dead leaves and dung from the surface to the lower soil levels, than occurred in the cloverless plots, which had much lower and less active worm populations. Worm casts are higher in available P than the surrounding soil[25] and Evans has shown[13] that a large amount of casting occurrs within the burrows and surrounding soil air-spaces.

The addition of superphosphate increased the soil P in all cases, despite the greater uptakes of P by both grasses and clovers in the superphosphated grass-clover plots of the N.R. series. Where lime by

itself was applied it had no effect on soil P levels, but where applied in addition to superphosphate the increase in amount of available P in the soil was considerably greater than that from superphosphate alone.

A comparison between equivalent sub-treatments in the N.R. and F.R. series shows that the effect of the return of dung and urine on the available soil P, was to produce an average difference over all sub-treatments of at least 50 lb P_2O_5 per acre in favour of the F.R. series.

The absence of any increase in production or in leaf levels of P following superphosphate application in the F.R. grass-clover plots, despite a considerable increase in the available soil P, suggests that P was not limiting to growth in this series.

Base Status and pH

There was no great variation in base exchange capacity between the sub-treatments, those plots with the higher organic matter being slightly higher than the others. There were, however, marked differences between treatments in the percentages of base saturation. They were lowest where there was the greatest nett loss of cations, i.e. where there was neither liming nor return of dung and urine, while those plots receiving both lime and dung and urine were almost completely saturated.

The soil reaction follows the same trends, both liming and the dung and urine causing definite increases in pH.

Calcium

The degree of calcium saturation was in all cases relatively high, being lowest in Sub-treatment 2 N.R. (where it was 46 per cent.), presumably because it was here that the nett losses of calcium were greatest. The addition of superphosphate to the grass-clover N.R. plots compensated for some of the calcium losses, as was found by Doak[26]. The addition of lime or the return of dung and urine produced a still more noticeable improvement in Ca status. This suggests that with high-producing pastures and heavy stocking by sheep on this soil, only occasional small additions of lime are necessary to correct for losses in leaching and in stock products.

Magnesium

The Mg status of the soil is very low; compared with the normal ratio of 3 of Ca to 1 of Mg on the exchange complex of soil of this type, the soils of these plots had between 9.8 and 18.6 m.e. of Ca, but no sample showed more than 1.5 m.e. of Mg. However, there were no obvious symptoms[27] of Mg deficiency in any of the herbage on the plots.

The exchangeable Mg generally tended to be higher where dung and urine were returned. The relative differences were, however, not as great as those for exchangeable Ca and K. Lime by itself does not appear to have caused any decrease in available Mg. The addition of superphosphate, however, effected a reduction in the level of exchange-

able Mg in the soil in both the F.R. and N.R. series. As this could hardly be due to displacement by the Ca (since the lime did not show such a definite effect) it would seem that in the presence of ample phosphate more Mg may have been utilised by the plants.

Many workers have found positive correlations between the amounts of Mg and P in plants, and have suggested that they are related in assimilation and metabolism.

Potassium

By overseas standards, the exchangeable K of this soil, in common with many New Zealand soils, is high. The most marked difference between treatments is the much lower exchangeable K in the soil of the N.R. series than of the F.R. series. This was also reflected in the K levels of the herbage. However, such marked differences in the exchangeable K levels of the soil may not occur on naturally grazed pastures, even where the stocking rate is high. It is possible that within normal urine patches concentrations are so high that the exchange complex is unable to absorb all the urinary K. Thus under field conditions, leaching losses of K may be greater than occurred on this plot series where the urine was distributed more evenly than under normal grazing.

It will be seen that K levels follow a pattern similar to those of Mg, but at lower levels in the N.R. series, and at higher levels in the F.R. series.

Soil Aggregation

The following general conclusions were drawn from Watkin's aggregation studies in 1948[20]:

(1) In the soils of the grass-clover sub-treatments there were slightly lower total aggregates (0.15-4 mm diam.), and higher proportions of smaller particles (0.15-<1.2 mm), than in the cloverless plots.

(2) The dung and urine return had little effect on soil aggregation in the cloverless sub-treatments, but in the grass-clover sub-treatments caused marked increases in the proportions of larger aggregates (>1.2 mm diam.), at the 6-9 in. depth. At the other depths there were no differences.

(3) The greatest degree of aggregation, and the greatest proportion of larger aggregates occurred at the 4-6 in. levels in all plots.

Earthworm Populations

The estimated numbers and weights of the earthworm populations are shown in Table II. The figures are the means from the counts on duplicate plots in each sub-treatment. Some of the inconsistencies

between the separate estimates are probably due to the differences between sub-treatments in the dates of hatching and maturity of the worms, as well as to sampling variation, but despite this variability there were some outstanding features clearly shown by the estimates:

(1) There is a strong positive correlation between the weights of earthworms and the pasture production; the cloverless N.R. sub-treatments had a population of approximately one million per acre, weighing about 4 cwt, while the upper extreme is in Sub-treatments 2-5 F.R. with populations of three million per acre, weighing over 18 cwt. It will be seen that, allowing approximately 1000 lb D.M. per acre per year for the maintenance of one sheep weighing 150 lb, the weights of earthworms in the soil were very close to the weights of stock able to be carried on the herbage grown in the treatments.

(2) The individual worms in Sub-treatments 2-5 were consistently heavier than those in Sub-treatments 1 and 6. The individuals in Sub-treatments 2-5 F.R. were slightly larger than in Sub-treatments 2-5 N.R., but the reverse held for Sub-treatments 1 and 6.

(3) The worm population consisted mainly of *Allolobophora caliginosa* and *Lumbricus rubellus* with the larger species *Octoclasium cyaneum* and *Allolobophora longa* occurring only infrequently. In the cloverless sub-treatments of both the N.R. and F.R. series, *A. caliginosa* accounted for over 90 per cent. of the total number and over 80 per cent. of the total weight, while *L. rubellus* made up about 6 per cent. of the total number, and 8 per cent. of the total weight. In the grass-clover associations on the other hand, *L. rubellus* contributed about 20 per cent. of the number, and 30 per cent. of the total weight.

TABLE II. EARTHWORM POPULATION OF THE MOWING SERIES

Treatment	Numbers (000s per acre)				Weight (cwt per acre)				Mean Weight per worm (g.)
	Sept. 1947	Sept. 1948	Sept. 1950	Average	Sept. 1947	Sept. 1948	Sept. 1950	Average	
No Return of Dung and Urine									
Sub-treatment 1	520	960	1050	843	2.2	4.1	4.8	3.7	0.224
2	2440	3400	2140	2660	14.4	17.1	12.4	14.6	0.281
3	2180	2440	1870	2163	12.8	13.6	11.7	12.7	0.298
4	2010	3960	1610	2527	15.0	19.8	10.6	15.1	0.303
5	2400	2960	2050	2470	16.4	15.4	12.2	14.7	0.302
6	1040	1440	1050	1177	4.0	7.2	4.5	5.2	0.227
Full Return of Dung and Urine									
Sub-treatment 1	920	2220	2260	1800	2.7	10.5	7.8	7.0	0.198
2	2400	3610	3400	3137	14.6	23.0	18.3	18.7	0.302
3	1920	3140	2700	2587	17.0	20.5	14.8	17.4	0.342
4	1740	3140	3310	2730	14.6	20.0	18.4	18.0	0.334
5	1870	3480	2660	2670	18.4	21.8	17.5	19.2	0.366
6	920	2830	2390	2047	3.3	14.1	7.6	8.4	0.208

Grass-grub Populations

The grass-grub larvae were distributed somewhat similarly to the earthworms except that there were less in the grass-clover F.R. groups of plots than in the grass-clover N.R. group. The data are not shown in detail, but there appeared to be no difference between the different fertiliser treatments, and the populations were obviously grouped into only four main divisions similar to the herbage production and the earthworms. The cloverless N.R. treatments had approximately 0.2 million, the cloverless F.R. treatments, 0.3 million, the grass-clover N.R., 1.3 million, and the grass-clover F.R., 1.0 million larvae per acre. The data were analysed on the basis of valid randomisation and showed that the N.R. and F.R. groups of the cloverless and the grass-clover plots were not significantly different, but that the cloverless and the grass-clover groups differed at the 1 per cent. level of significance.

During the pasture trial there was no visible damage from grass-grubs, but it must be remembered that soil moistures were relatively high throughout this trial. In addition, the intensive grazing and motor mowing was undoubtedly of considerable benefit to the rooting of the plant tillers.

General

Despite the limitations described in the introduction the results presented above give a consistent pattern of soil development, particularly when the soil data are considered together with the pasture yields and composition. The total data are consistent with the normally accepted New Zealand system of soil fertility building with clovers, superphosphate, lime, and other minerals where needed to meet original or induced soil deficiencies, and the return of dung and urine from the grazing animal. The earthworms, by their incorporation of the dung and other residues into the soil, and by their burrowing, soil mixing, and also their excretory activities, undoubtedly play an important and beneficial role in soil structure improvement and in general soil fertility increase.

It is of interest to compare the nitrogen fixation by the clovers in this experiment, with other estimates. In the N.R. series a comparison between the fertilised cloverless and the grass-clover treatments shows that the extra nitrogen removed in the grass-clover herbage amounted to approximately 500 lb per annum. To this must be added the extra nitrogen in the soil which in the top 2 in. of soil at the end of the experimental period amounted to 200 lb N per acre (0.04 per cent. of approximately 500,000 lb per acre dry soil). Thus, even without allowing for leaching or other losses, the most conservative estimate of the annual nitrogen increase through the clovers in this series, is approximately 550 lb N per acre.

This quantity is several times greater than those recorded by Karraker[8], who, in his lysimeter trials estimated an average annual N fixation by white clover of 120 lb per acre, made up of 40 lb in the clover herbage, 50 lb in the drainage, and 30 lb increase in the soil, the latter being measured to a depth of over 10 in. Similarly, there was

an annual N increase from red clover of 140 lb, made up of 60 lb in the herbage, 40 lb in the drainage, and 40 lb in the soil. On the other hand, Johnstone-Wallace[28] measured an extra 200 lb N per acre in grass–white-clover mixtures above that in pure grass pasture at Cornell, and Russell[2], after examining data on annual nitrogen fixation by clovers, considers an annual amount of 250-350 lb per acre as typical of the fixation by good clover or lucerne.

There is little doubt that the very high nitrogen fixation by the clover in this experiment is a reflex of the superior growth ability of the pedigree N.Z. strain of white clover used, and the temperate climatic conditions, which allow a continued clover growth and probably fixation of N throughout the year. The characteristics and field performance of the N.Z. pedigree clovers have recently been described by Corkill[29]. Some additional information is available from a recent replicated field trial at Palmerston North[30] in which there is included a comparison between the total N uptake in a mown pasture of grass and pedigree N.Z. white clover, and a pasture of grass and a "natural" strain of white clover graded below the N.Z. certification standard. The technique used was as for the Mowing N.R. series of this experiment, and the clovers were both sown with ryegrass only.

In the second year of the trial, after the clover was well established and in fact when the poor clover type was at its peak of growth and density in the pasture, the total N uptake in the herbage of the pedigree white clover pasture was 460 lb per acre, of which 330 lb was in the clover and 130 lb in the grass. In the pasture containing the poor type clover, the total uptake was 260 lb per acre, of which 150 lb was in the clover and 110 lb in the grass. The data for this pedigree clover series agree well with the estimates for Sub-treatments 3 and 5 of the N.R. series of this experiment.

In addition to demonstrating clearly the superiority of the pedigree clover, the data also makes obvious the need for caution in regional comparisons without knowledge of the clover strain used in each trial.

Without data for leaching losses and for the gaseous losses from urine patches, it is not possible to estimate the nitrogen fixation by the clovers in the F.R. series. It is, however, of considerable interest that the nett advantage of the white clovers in the mixture are similar in both the N.R. and F.R. series. Thus can be seen the self-balancing action in an evenly grazed grass–white-clover pasture, with the urine patches having a temporary very high soil nitrogen and thus a grass dominance, and the remainder of the paddock acting continually as a nitrogen-fixing reservoir through the clovers. The actual residual values to crops of the soil fertility levels reported in this paper, and the significance of the evenness of the return of dung and urine over the pasture area, are discussed in subsequent papers of this series.

Acknowledgement

The authors wish to thank Mr. B. R. Watkin, Grasslands Division, for permission to use some of his soil analytical results.

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PASTURE GROWTH AND SOIL FERTILITY

IV. THE INFLUENCE ON SOIL FERTILITY OF CLOVERS, SUPERPHOSPHATE, LIME, DUNG AND URINE APPLIED TO THE PASTURES, AS MEASURED BY THE GROWTH OF SUBSEQUENT FORAGE CROPS.

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(Received for Publication, 20 October 1952)

Summary

(1) Yields and composition are presented of rape, maize, and Italian ryegrass crops grown subsequent to the pasture treatments described in Part I.

(2) The total growth and the quantity of nutrients removed in the first rape and maize crops after the pasture, were closely correlated with the previous pasture yields.

(3) There were large differences in leaf colour and in growth habit, and these differences are discussed in relation to the nutritional status of the soils.

(4) Differences between treatments were very much reduced in the second cut of the rape crop, and the subsequent crops of ryegrass and rape were uniformly poor.

(5) Differences in levels of soil N appeared to be primarily responsible for differences between treatments, but there were also visible indications of Mg deficiency in the first rape crop grown after the limed grass-clover N.R. pasture treatment.

INTRODUCTION

THE influence of clovers, superphosphate, lime, and dung and urine on pasture yields and composition were reported in previous sections of this series[1,2,3]. Large increases in pasture productivity due to the clovers and the value of dung and urine in maintaining the soil nutrient levels were demonstrated. From the data and the literature cited in the previous sections it could reasonably be expected that there would be a wide range in the growth of soil-exhautsing crops grown subsequent to the pastures.

On the wide question of the soil-fertility increase from pastures, there is of course a background of knowledge nearly as old as agriculture itself. There is no doubt that pastures play a major part in the building and maintenance of soil fertility, as measured by: (1) pasture production itself; (2) improvement of soil structure; (3) a decrease in soil erodibility; and (4) growth of subsequent crops. For a geographical and historical coverage of farm practices and experimental data on the subject, reference may be made to several recent reviews[4,5,6] and to Russell's standard text[7]. Other relevant data include those presented by Snider[8] and Karraker[9] in the United States, and by Mann[10] in England. In Australia, Woodroffe, Sims, Jardine, Bath, and Penman[6] have all recently demonstrated the importance of clovers grown in rotation with cereals. They show that subterranean clover pastures have resulted in increases in stock carrying capacity, in higher soil fertility levels as measured by organic matter, structure, nutrient concentrations and in the growth of subsequent wheat crops.

There is, however, very little quantitative information on the many factors and mechanisms involved, and Davies[6] has recently emphasised that while there may be a large body of empirical knowledge on the subject, much of it should be examined critically, especially in relation to the modern practices linked with ley farming.

The length of time during which soil improvement effected by pastures will last under arable cropping depends of course on several factors. In low rainfall regions the benefits appear to last for several years, but with high rainfall the effect is of much shorter duration. Even though he is able to cite British evidence of the value of one-year grazed clover pasture lasting through three arable crops, Russell considers that it is probably wiser to assume that the second and third year residual effects of such a pasture are small. On the other hand, he quotes evidence to show that the effects of a three-year cut lucerne stand were similar to those of a grazed three-year ryegrass-clover pasture, and that both gave definite residual benefits to subsequent crops for at least three years. Jacks[4] concludes from his survey of published data that the full soil structure building effect of a ley is normally destroyed by cultivation within two years in moist temperate conditions.

In New Zealand there has been very little direct measurement of the residual soil fertility effects of different pastures, although here again there is a considerable background of farming experience on the subject. New Zealand is essentially a country of permanent pastures, and rotational grain cropping is common only in the South Island and in certain small areas of the North Island[11]. As a result there is not, in the pastoral areas, the same appreciation of the value of pastures in increasing soil fertility and improving soil structure, as there is in regions where cultivation and cropping are annual practices. In the Canterbury area where grain cropping is a major intrest, there is a growing body of field experience[12,13] and statistical evidence[14] all pointing to a general rise in crop yields following the improvement of pastures through the use of better pasture species, and through better management.

Direct experimental evidence is limited to the very short-term trial results recently published from this Division[15], and to the preliminary results from a long-term replicated field trial at Lincoln College, where a study is being made of the effects of various cropping and pasture rotations[16].

The very wide range of pasture types induced during the first four years of this trial presented an excellent opportunity of determining the relationship between the growth of arable crops and the previous pasture performance.

Experimental Methods

The design of the experiment and the treatments imposed have been described in Part I.

At the end of August, 1950, the grazing series of pasture plots was ploughed (4 in.), cultivated, and sown with certified N.Z. Rape *(Brassica napus)*. This was drilled in rows 18 in. apart along each plot at the rate of 2 lb per acre. The rape growth was harvested by two cuts, the main growth on 3 January, 1951, and the recovery growth

on 6 March, 1951. The area was then cultivated again and sown with Pedigree N.Z. Italian ryegrass, broadcast at 60 lb per acre. The ryegrass growth was harvested with mower cuts on 10 July, 1951 and on 5 September, 1951. In October, 1951, after the second cut from the ryegrass, another rape crop was sown, using the same line of seed and methods as before. In all these cultivations great care was taken to avoid plot-to-plot soil transfer. All herbage was discarded from the area after sampling.

During the first year of the cropping on the grazing series the mowing series of the pasture trial were continued, largely as a demonstration area. Dung and urine were obtained from other trials and the calculations of the required amounts were based on 1949/50 data. However, in October, 1951, the mowing series were also ploughed, cultivated and sown to crops for residual fertility measurements. One complete set was sown to rape as for the grazing series while the duplicate set was planted with maize *(Zea mays)* of the variety "Reid's Midland hybrid U. 68", in 21 in. rows at 2 in. spacings. Measurements on the rape and maize crops were completed by February, 1952.

RESULTS AND DISCUSSION

Rape Crop after the Grazing Series—First Cut

The ploughing and cultivation of the grazing plots brought to light certain visible differences in the soils, resulting from the various pasture treatments. In the N.R. series the soil of the cloverless plots was of a greyish-to-light-brown colour, showed a distinct glaze on the turned furrow, and was poor in texture. The soil in the corresponding grass-clover plots was much darker in colour (Fig. 1). An improve-

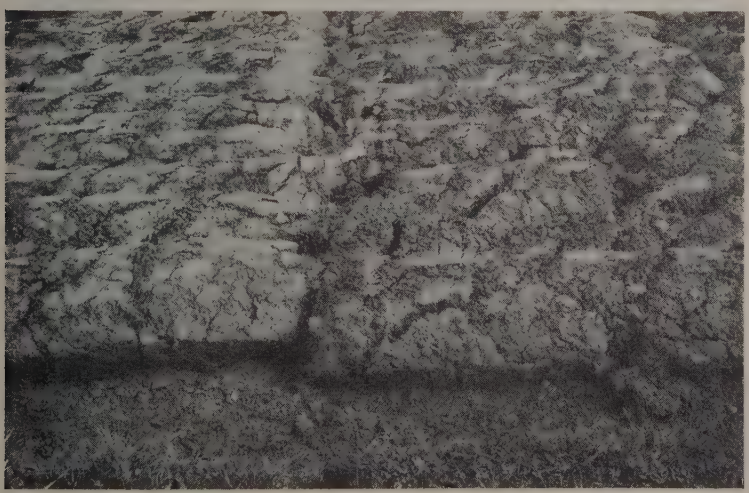

FIG. 1. Differences in soil texture and colour at the first ploughing of the Grazing N.R. series. On the right is the open-textured dark soil of Sub-treatment 5 (grass+clover+superphosphate+lime); the soil of Sub-treatment 6 on the left (grass alone+superphosphate+lime) shows a distinct glaze on the furrow-slice, and the soil was more sticky in texture.

ment in texture was evident in Sub-treatments 2 and 3, but this improvement was less marked in the limed Sub-treatments 4 and 5. In the F.R. series there was again a difference in colour and texture between the soils of Sub-treatments 1 and 6 and those of 2-5: the latter were all dark in colour and of excellent texture.

By mid-November the rape growth on Sub-treatments 1 and 6 was noticeably poorer and lighter in colour than the others. Differences became progressively greater until at the time of the first cut (3 January, 1951) the area was a mosaic of plot growths of different sizes and graduations in leaf colour, from yellowish-brown to dark blue-green. The following brief notes were made on the appearance of the plots at this stage (Fig. 2):

Fig. 2. Portion of the rape crop on the Grazing F.R series, 10 days prior to the first cut. Sub-treatment 5 is on the right front; Sub-treatment 6 (4 rows per plot) is on the left front.

Sub-treatment 1 N.R.: Low growth (about 8 in.) on thin stalks; papery leaves of yellowish-green colour with red marginal tinges; brown patches in older leaves, and many dead leaves on the ground.

Sub-treatment 6 N.R.: Growth similar to that of Sub-treatment 1, but without the same amount of red colouration in the leaf margins.

Sub-treatment 2 N.R.: Erect growth (about 20 in.) with leaves mainly medium-green, but with some yellowish mottling of the interveinal spaces; red-purple colouration on the outer margins of the older leaves.

Sub-treatment 3 N.R.: Erect growth (about 24 in.) with leaves darker green than Sub-treatment 2 and with a bluish tinge throughout; no yellowish mottling and only a reddish tinge on the leaf margins.

Sub-treatment 4 N.R.: Growth at the same height as Sub-treatment 2, but with the older leaves markedly mottled by much light green

tissue in the interveinal spaces over the whole leaf area; leaf margins markedly tinged with red-purple colour, but not so obvious as in Sub-treatment 2, possibly on account of the mottled leaf surface.

Sub-treatment 5 N.R.: Growth slightly lower than Sub-treatment 3, but otherwise very similar in appearance throughout.

Sub-treatment 1 and 6 F.R.: Low dense growth (about 8 to 10 in.) with the same pale yellowish-green leaf colour as in Sub-treatments 1 and 6 N.R., but with less browning of the older leaves; both sets of plots showed a relatively high intensity of red colouration of leaf margins.

Sub-treatments 2, 3 and 5 F.R.: Very tall growth (about 30 in.) with dark bluish-green leaves, without any yellow mottling and with only a slight red-purple tinge on the leaf margins.

Sub-treatment 4 F.R.: Tall growth only slightly shorter than Sub-treatments 2, 3 and 5, with the leaf colour a similar dark bluish-green; a slight amount of yellow mottling in the older leaves.

Comparison of these colours with examples given by Wallace[18] indicated that the yellow-brown colour was due to N deficiency and the red-purple tinging to P deficiency. The yellow interveinal mottling, so pronounced on Sub-treatment 4, appeared to be similar to the symptoms of Mg deficiency.

Table I is a summary of the yields and composition of the rape crop, the values being the averages for the three replicates in each paddock. The 95 per cent. Confidence Limits for the mean D.M. yields were calculated on the basis of full randomisation within each block. The chemical data presented are a recalculation of the separate analyses on the "leaf" and "stem" samples; as the crops were used only as indices of changes in soil fertility under the various pasture treatments the presentation of these results is not warranted. However, mention of a few of the differences between the rape leaf and stem tissue will assist in the interpretation of the total yield data.

(1) The leaves had much higher D.M. percentages than the stems; in the low-producing Sub-treatments 1 and 6, the average D.M. content of the leaves was 22.4 per cent. (20.8-25.1 per cent.), and that of the stems, 13.9 per cent. (12.6-14.9 per cent.); in the high-producing Sub-treatments 2-5, the average D.M. content of the leaves was 16.8 per cent. (13.9-19.0 per cent.) and that of the stems, 9.7 per cent. (8.6-10.8 per cent.). The much lower differences between treatments in dry weight than in green weight can therefore be appreciated, as the differences in green weight yield are increased by the higher water content of the tall stem-tissue of the heavier crops.

(2) The N levels in the leaf tissue were approximately twice those of the stem tissue in all cases.

(3) There was no consistent difference between leaf and stem in levels of Ca or of P.

(4) The levels of K were approximately 50 per cent. higher in the stem than in the leaf tissue.

TABLE I. YIELDS AND COMPOSITION OF RAPE GROWN SUBSEQUENT TO THE GRAZING SERIES

Treatment	Total Yield Green-weight (lb per acre)	Ratio of Stem to Leaf Green-weight	D. M. % (Total Herbage)	Total Yield of D. M. (lb per acre) and 95% Confidence Limits*	Ratio of Stem-to-Leaf Dry Matter	Chemical Composition (% of D.M.)				Nutrients in Crop (lb per acre)			
						N	Ca	K	P	N	Ca	K	P
	MAIN CROP: 24.10.50 - 3.1.51												
F. R. 1	21226	1.57	17.0	3599 ± 411	0.99	1.12	1.39	2.56	0.31	40.2	50.2	92.1	11.0
" 2	49966	1.99	12.7	6345 " "	1.12	1.72	1.89	2.81	0.35	108.9	119.7	178.2	22.2
" 3	59843	2.53	11.8	7087 " "	1.52	1.89	1.63	3.00	0.36	134.0	115.5	212.8	25.5
" 4	43071	1.77	12.7	5454 " "	1.00	1.75	2.03	2.68	0.34	95.4	110.8	146.2	18.8
" 5	54597	2.07	12.0	6543 " "	1.12	1.74	1.83	2.76	0.32	114.1	119.6	181.2	21.3
" 6	16617	1.28	17.1	2847 " "	0.79	1.12	1.53	2.52	0.31	32.0	43.6	71.6	8.9
F. R. 1	24512	1.42	17.9	4388 ± 610	0.84	1.03	1.42	2.47	0.28	45.2	62.2	108.5	12.5
" 2	72160	2.41	11.4	8260 " "	1.41	2.14	1.49	3.41	0.37	177.0	122.9	281.5	30.3
" 3	73125	2.57	11.1	8105 " "	1.58	2.21	1.55	3.63	0.39	179.3	126.1	294.5	31.6
" 4	65306	2.54	11.4	7460 " "	1.56	2.15	1.68	3.48	0.37	160.4	125.4	259.6	27.8
" 5	71889	2.58	12.0	8660 " "	1.52	2.28	1.41	3.42	0.39	197.6	122.5	295.9	34.1
" 6	20567	1.20	18.0	3705 " "	0.76	1.19	1.53	2.58	0.30	44.2	56.9	95.5	11.4
	RECOVERY GROWTH: 3.1.51 - 6.3.51												
N. R. 1	8101	0.74	17.0	1379 ± 323	0.59	1.90	1.95	2.92	0.38	26.2	26.9	40.3	5.2
" 2	10330	0.85	17.9	1852 " "	0.68	1.80	2.01	2.80	0.37	33.4	37.2	51.8	6.8
" 3	11642	0.89	18.2	2119 " "	0.65	1.70	2.01	2.79	0.37	36.0	42.5	59.1	7.7
" 4	8678	0.90	17.4	1509 " "	0.76	2.02	2.02	2.70	0.39	30.6	30.7	40.8	5.9
" 5	11651	0.98	17.7	2066 " "	0.75	1.82	2.18	2.54	0.38	37.6	45.0	52.3	7.9
" 6	7918	0.90	18.2	1442 " "	0.65	1.72	2.04	2.78	0.37	24.8	29.5	40.1	5.3
F. R. 1	9227	0.85	17.9	1651 ± 497	0.65	1.71	1.75	3.01	0.34	28.2	29.0	49.8	5.7
" 2	13745	0.92	17.7	2434 " "	0.69	1.67	1.72	3.05	0.32	40.7	42.0	74.2	7.9
" 3	15678	0.95	16.0	2494 " "	0.77	1.60	1.77	3.06	0.34	40.0	44.3	76.4	8.5
" 4	14202	0.83	17.0	2418 " "	0.60	1.71	1.82	2.80	0.34	41.3	44.1	67.8	8.3
" 5	13403	0.76	16.8	2249 " "	0.66	1.58	1.95	2.87	0.34	35.6	43.9	64.7	7.6
" 6	9787	0.88	18.6	1825 " "	0.72	1.52	1.80	2.66	0.34	27.7	32.9	48.5	6.2

* Calculated on the basis of complete randomisation.

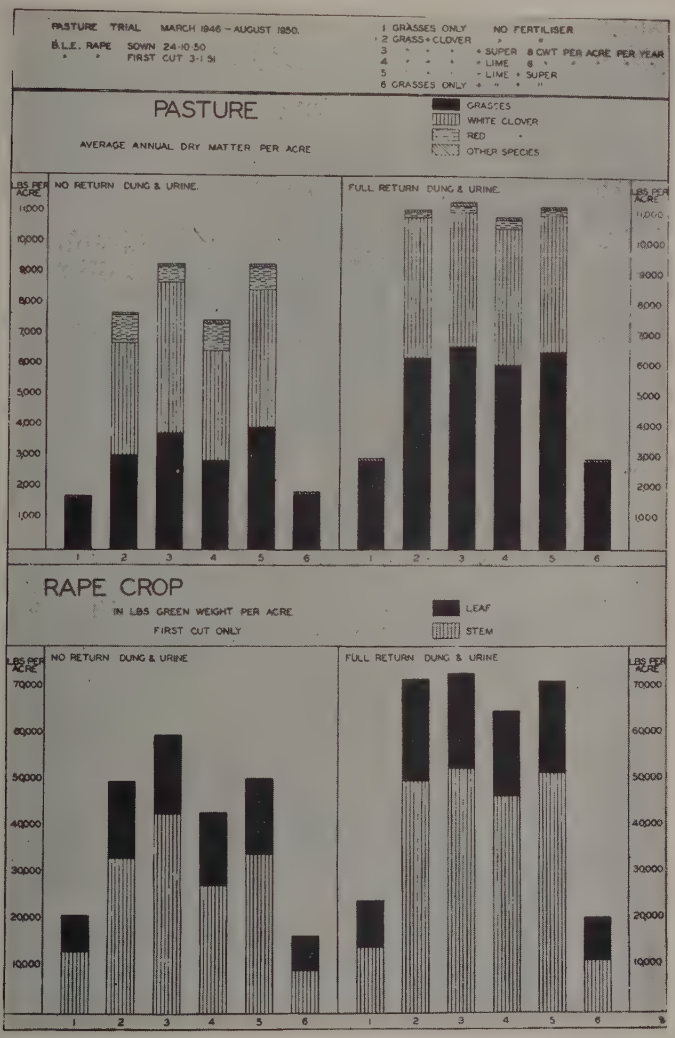
PASTURE TRIAL MARCH 1946 – AUGUST 1950.
B.L.E. RAPE SOWN 24-10-50
FIRST CUT 3-1-51
1 GRASSES ONLY NO FERTILISER
2 GRASS + CLOVER
3 " " + SUPER 8 CWT PER ACRE PER YEAR
4 " " + LIME 8 " " " "
5 " " + LIME + SUPER
6 GRASSES ONLY " " "
PASTURE
AVERAGE ANNUAL DRY MATTER PER ACRE
GRASSES
WHITE CLOVER
RED
OTHER SPECIES
NO RETURN DUNG & URINE.
FULL RETURN DUNG & URINE.
LBS PER ACRE
RAPE CROP
IN LBS GREEN WEIGHT PER ACRE
FIRST CUT ONLY
LEAF
STEM
NO RETURN DUNG & URINE
FULL RETURN DUNG & URINE

FIG. 3. Yields of pasture and the subsequent rape crop (main cut) on the Grazing Series.

Yields, both in terms of green weight and dry weight, followed a similar pattern to those of the previous pastures (Fig. 3). It can also be seen that increases in total yield are paralleled by increases in the ratio of stem to leaf. Thus for the lowest yielding crop (Sub-treatments 1 and 6 N.R. and F.R.), the total green-weight yields were approximately 20,000 lb per acre with a stem-to-leaf ratio of 0.8. Between these two low-producing plots there was, however, a significantly greater yield in Sub-treatment 1 than in Sub-treatment 6. There was then a large increase in yield to Sub-treatment 4 N.R. which had

a green weight yield of 43,000 lb per acre with a stem-to-leaf ratio of 1.8, and a dry matter yield of 5,500 lb per acre, with a stem-to-leaf ratio of 1.0. Increases above this follow parallel courses, both the green weight and the dry matter yields rising in steps of approximately 5,000 lb of green weight and approximately 750 lb of dry matter, for Sub-treatments 2, 5, 3 of the N.R. and for Sub-treatments 2 to 5 of the F.R. series in that order. The increasing yields are accompanied by steady increases in the proportion of stem, the stem-to-leaf ratios increasing to 2.6 and to 1.6 for the green weight and dry matter yields respectively. Thus it is seen that the factors affecting residual soil fertility as measured by this rape crop were:

(a) The return of dung and urine to the pasture resulted in an increase of 34 per cent. in the green weight and 27 per cent. in the dry matter of the subsequent crop. These figures are obtained by comparing the yields of the N.R. and F.R. series as two complete groups.

(b) The crops following the grass-clover pastures had three times the green weight, and twice the dry matter yield of the crops following the cloverless pastures.

(c) The pasture increases in the grass-clover N.R. sub-treatments secured by the application of superphosphate, were paralleled by increases in the subsequent crops of approximately 23 per cent. in green weight, and of 16 per cent. in D.M. yields.

(d) In the N.R. series the use of lime was followed by decreased yields associated with a distinct yellowish mottling of the leaves. A similar, but not so marked effecte was seen in the limed plots of the F.R. series.

From the chemical compositions as shown in Table I several points are clearly demonstrated:—

(1) The N level of the rape crop was considerably greater where clover had grown; the average result was an increase from 1.1 per cent. N in the cloverless, to 1.8 per cent. N in the grass-clover plots of the N.R. series, and similarly increases from 1.1 per cent. to 2.2 per cent. N in the F.R. series. The N levels in Sub-treatments 2-5 were 1.8 per cent. in the N.R. series and 2.2 per cent. in the F.R. series, a reflection of the effect of dung and urine on the grass-clover mixtures. On the other hand there was no difference between the nitrogen levels of the crops on any of the cloverless sub-treatments.

(2) Ca levels were highest in Sub-treatment 4 of both the N.R. and F.R. series by about 20 per cent., while the levels in Sub-treatments 2-5 N.R. were generally higher than in the corresponding F.R. plots. In both paddocks the Ca level in Sub-treatment 6 was slightly higher than in Sub-treatment 1.

(3) K levels showed increases after clover growth (2.8 per cent. compared with 2.5 per cent.) and there was a further increase due to dung and urine (3.5 per cent. compared with 2.8 per cent.).

(4) P levels showed increases due to clovers (0.34 per cent. compared with 0.31 per cent. in the N.R. series) and a further increase in Sub-treatments 2-5 due to dung and urine (0.38 per cent. compared with 0.34 per cent.). There was no consistent increase in leaf levels of P following the superphosphate applications.

The above differences in chemical composition, when coupled with yield data, result in large differences in total nutrient removal from the soil by the crops grown after the various pasture treatments. A comparison of the crop green weight yields with the previous pasture productions shows a very strong correlation; this agreement is less marked when the effects of the differences in D.M. percentage in the crops are considered, but the correlation again becomes stronger when the differences in nutrient levels are taken into account. Thus, there is a wide range of nutrient uptake by the crops, rising from that of the treatments which had previously the lowest pasture production (Sub-treatments 1 and 6 N.R.) up to those of the previously highest in pasture production (Sub-treatments 2-5 F.R.). In terms of artificial fertilisers the crop nutrient uptakes by the crops on these extremes were as follows:—

	Sub-treatments 1 and 6 N.R. (lb/ac)	Sub-treatments 2-5 F.R. (lb/ac)
Sulphate of ammonia	175	900
Carbonate of lime	112	312
30 per cent. K Salts	321	1162
Superphosphate	114	342

It is also apparent that the total nutrient uptakes by the crop followed a pattern which could have been predicted by the previous pasture history. This applies for N, and P, and for K, except for the lower levels in Sub-treatments 4 and 5 of the N.R. series. It is of interest to note as a comparison with these data, that the yield and composition of a good rape crop in Britain is usually considered as being 5,000 lb D.M. per acre, containing 2.5 per cent. N, 0.4 per cent. P, 2.7 per cent. K, and 2.0 per cent. Ca[19].

Rape crop after the Grazing Series—Second Cut

In the recovery growths up to the time of the final cut on 6 March, 1951, there was a reduction of differences among plots, both in total growth and in leaf colour. Leaf colour in all plots was greyish-green with a fairly general incidence of red-purple colour on the leaf margins. The only visible differences were slightly better growth and darker green leaf colour in Sub-treatments 3 N.R. and 2-5 F.R.

It will be seen from Table I that this reduction in variability in appearance was accompanied by similar trends in green weight yields, leaf-stem ratios, D.M. percentages, and chemical compositions.

Comparing the regrowth with the first cut there are several points of interest:

(1) The recovery growth was only about a quarter that of the main cut, although the growth period was approximately the same. This difference was probably due to: (a) the drier weather and soil conditions; and (b) the reduction in soil nutrients due to the discarding of all the herbage from the first cut. It is of interest in this regard to compare these plot yields with the yield of a neighbouring paddock on the same soil type, in which a rape crop was grown as part of another trial. This paddock had a pasture

treatment similar to that of Sub-treatment 5 F.R. over the same period, and cultural operations, sowing and grazing coincided with those of the plot trial. The rape crop was, however, grazed by sheep with a normal return of dung and urine. Growth and N levels of this grazed crop for the first period (8,500 lb D.M. per acre—2.3 per cent. N) were very similar to those of the highest yielding of the plots. The recovery growth on the grazed paddock during the second period was, however, of a much darker green colour, and the yield (4,000 lb D. M. per acre—4.0 per cent. N) was over twice that of the best yielding plot.

It seems reasonable, therefore, to consider the reduction in the grazed paddock yield from 8,500 lb D.M. to 4,000 lb D.M. per acre as being a reflex of the seasonal growth difference, and the difference between the recovery growth on the paddock and that of the highest yielding of this plot series (2,500 lb D.M. per acre—1.6 per cent N) as being an index of the soil nutrient loss from the non-return of dung and urine.

(2) Between treatments there were no definite differences in N levels of the total herbage in the recovery growths. This reduction in differences of the N percentages was due to a combination of a rise in the levels in Sub-treatments 1 and 6 and a fall in Sub-treatments 2-5, the latter being more clearly seen in the F.R. series.

(3) Ca levels showed a general rise in all plots except in Sub-treatment 4 N.R. which remained constant.

(4) There was a slight rise in all leaf K levels except in Sub-treatments 2-5 F.R. which showed a slight reduction. On the other hand there was a general reduction in K levels in all stem tissue. There was also a reduction in the relative amounts of stem growth. The nett result was a levelling of the K content of all plot yields.

(5) P levels declined in Sub-treatments 2–5 F.R., but increased in all others. Differences between treatments were much less than for the first cut.

The general conclusion which can be drawn from this section is that the higher soil fertility, induced by vigorous pasture growth, was largely dissipated through the growth and removal of the subsequent rape crop, growing for a period of only five months. The regrowth of the rape crop showed only minor differences in yield and chemical composition.

Italian Ryegrass Crop

There were no differences among the plots in the appearance, yield, or composition of the ryegrass crop taken subsequent to the rape crop. All ryegrass herbage yields were low compared with normal growth of this species sown at the same time on highly fertile soil. The growths on all plots were characterised by a yellowish-green colour typical of nitrogen deficiency.

Yields and chemical compositions were determined, but are not presented because of lack of any significant differences between

treatments. Yields varied between 3,048 and 3,410 lb D.M. per acre, and the average levels of N, Ca, K and P were 1.76, 0.54, 2.79, and 0.31 per cent. respectively. Yield and composition were similar to those of the mixed herbage previously grown on Sub-treatments 1 and 6 N.R.

Second Rape Crop after Grazing Series

Growth on all plots for this second rape crop was uniformly poor, the leaves being yellow-green with a small amount of red marginal tinting. There were no visible differences between plots and therefore individual plot yields were not determined.

The mean D.M. yield of the area, determined from several random samples, was 2,250 lb per acre. By comparison with the yields after the mowing series, it is obvious that this low yield was due mainly to low soil fertility. It is of interest to note that this yield is less than that produced on Sub-treatments 1 and 6 N.R. in the first crop after the mowing series.

Rape Crop after the Mowing Series

Due probably to the colder and wetter spring, the growth of all rape crops grown on the station was poorer in 1951/52 than in the previous season. In addition, whether from this cause or not, leaf colour differences were not so striking in this crop as in the previous year. No interveinal mottling and only a small amount of red marginal colouration was observed. The variation from yellowish-green to dark blue-green was, however, as obvious as in the previous year. Also the growth on the highest-producing plots was not as tall as in the previous year, the stems being on the average only about $\frac{1}{2}$-$\frac{2}{3}$ the height of their counterparts in the crop after the grazing series.

TABLE II. GROUPED YIELDS OF RAPE AND MAIZE CROPS
(lb D. M. per acre)

Treatments	Rape (1951) after Grazing Series	Rape (1952) after Mowing Series		Maize (1952) after Mowing Series	
	Treatment Yields	Treatment Yields	Headland Yields	Treatment Yields	Headland Yields
Sub-treatments					
1 & 6 N.R.	3,200	2,400	4,950	2,100	4.000
2 & 4 N.R.	5,900	5,550	5,100	4.500	5,000
3 & 5 N.R.	6,800	6,400	5,000	5,100	5,500
1 & 6 F.R.	4.050	2,700	4,200	3,600	6,100
2 to 5 F.R.	8,100	7,100	4,750	8,800	6,800

In Table II are shown the D.M. yields, the data having been grouped for this purpose into the combinations of treatments which were very similar in pasture yield, composition, and in subsequent crop yields. The figures are therefore the averages for at least pairs of sub-treatments. Also shown are similar data obtained from the measured samples along the headland areas of each plot. These give an index of the natural variability within the plot area, and can be used for adjustment of the plot yields to a more uniform base.

Even without any such adjustment, however, the trend of the yields in this crop follows very closely the crop grown the previous season after the grazing series; no detailed discussion of the data is therefore necessary.

Maize Crop after the Mowing Series

Large differences in leaf colour and growth were apparent early in the season, and increased continually up to the time of early flowering when the crop was harvested at the green-feed stage. Leaf colour varied from a pale yellow-green in Sub-treatment 1 and 6 of both series, through a slightly darker green leaf colour of Sub-treatments 2-5 N.R., to a very dark green in the leaves of plots 2-5 F.R. The height of plants ranged from 1½-2 ft in Sub-treatments 1 and 6 N.R. up to between 6 and 7 ft in Sub-treatments 2-5 F.R. (Fig. 4).

Fig. 4. The maize crop on the Mowing series just prior to measurement. View is from S.E.—see Fig. 1 in Section 1 for the plot layout—4 rows per plot.

D.M. yields are shown in Table II, grouped for this purpose on the same basis as for the rape yields in the same paddock. There is the same general pattern in the maize as in the rape yields, except for the slightly lower relative maize yields in Sub-treatments 2-5 N.R. In considering in detail these maize yields there is, however, an obvious need to make an adjustment based on the headland yields. Such adjustment does not result in any marked departure from the general pattern of crop yields on the first ploughing subsequent to the various pasture treatments. No discussion is therefore considered necessary on these total yield data.

In Table III are shown the results of chemical analyses made on the bulked maize herbage of Sub-treatments 1 and 6 F.R., and of 2-5 F.R. These groups were taken as being most representative of the conditions in normal practice as a comparison of the yields between those obtained when "run-out" and good pastures are ploughed for forage cropping purposes.

TABLE III. YIELDS AND COMPOSITION OF THE MAIZE CROPS FOR THE TWO MAIN GROUPINGS OF THE P.R. MOWING SERIES

Treatment	Herbage	Yields of Dry Matter (lb per acre)	D.M. (%)	Chemical Composition (% of D.M.)				Nutrients in Crop (lb per acre)			
				N	Ca	K	P	N	Ca	K	P
Sub-treatments 1 and 6 F. R.	Leaf	1800	21.6	1.22	0.40	2.35	0.30	22	7	42	5
	Stem and sheath	1800	12.5	0.51	0.28	3.17	0.36	9	5	57	6
	Total	3600	15.8	0.87	0.33	2.75	0.32	31	12	99	11
Sub-treatments 2 to 5 F. R.	Leaf	3700	22.7	1.70	0.46	2.13	0.26	63	17	79	10
	Stem and sheath	5100	13.5	0.61	0.24	2.80	0.22	31	12	143	11
	Total	8800	16.3	1.18	0.33	2.52	0.24	104	29	222	21

From these analyses there are several points of interest:

(1) By comparison with standard tables it is seen that the maize crop after the grass-clover F.R. pastures was similar in composition to that quoted by Morrison in the U.S.A.[20] as normal for corn fodder at a similar stage of maturity, and presumably grown on fertile soil; the only real difference lies in the lower N levels of the crops in this experiment. There seems little doubt that this lower N level was due to the very wet spring and summer, and the consequent excessive leaching of nitrate from the soil.

(2) The higher-yielding group of plots had a greater proportion of stem and sheath tissue than the shorter and lower-yielding group. In addition, the percentages of D.M. were slightly greater in the higher-yielding group.

(3) Both leaf and stem N levels were much higher in Sub-treatments 2-5 than in Sub-treatments 1 and 6; in both groups the leaf N levels were very much higher than those of the stem and sheath tissue.

(4) Ca levels were higher in the leaves than the stems in both groups, but there were no differences between the two groups.

(5) K levels were highest in the stems of both groups; the K levels of both leaf and stem were higher in Sub-treatments 1 and 6 than in Sub-treatments 2-5.

(6) There were no consistent differences in phosphorus levels, between leaf and stem, but the levels were higher in the low yielding than the high yielding group.

General

There are a few general matters concerning the results which are worthy of consideration:

(1) Rape and maize are very responsive to high soil fertility, and under good growth conditions both species take up very large amounts of soil N and minerals in short growing seasons. It is of course for this reason that they were chosen as soil fertility indices in this trial, but it must be appreciated that the yield differences recorded, and the

short period during which the soil fertility differences persisted, cannot necessarily be taken as directly applicable for other forage or grain crops. For example, there might have been much lower, but longer continued, differences between treatments, had wheat been used as the indicator crop, due to its lower total N and mineral uptake[7]. On the other hand, the leaching, which is presumed to be relatively high at Palmerston North, would act to eliminate any fertility advantage, built up by good pastures, much more quickly than would occur in relatively dry areas such as in Canterbury in the South Island.

(2) Comparing the maize with the rape crop data, it is seen that although the D.M. yields were similar, there were marked differences between the nutrients removed by the two crops. Moreover, there was a marked variation in the degree of difference between the high and low yielding groups within each crop. For example, Ca levels were all very much lower in the maize (0.3 per cent. of D.M.) than in the rape crop (1.4-1.7 per cent. of D.M.), while the K and P levels of the maize crop were higher in Sub-treatments 1 and 6 than in Sub-treatmens 2-5. The position was reversed in the rape crop. Such differences between crops naturally effect the valuation of the residual fertility from the previous pasture treatments. For example, the residual soil N value from the clovers, as measured in the F.R. series by the 1950/51 rape crop was approximately 140 lb per acre, but as measured by the 1951/52 maize crop was only 73 lb per acre. It is of interest to note also that both these estimates are very much lower than the estimates from the soil analyses given in Part III[3]. This, together with the lack of differences and the obvious nitrogen deficiencies in the subsequent crop growth, indicates considerable loss of soil N during the first cultivation and cropping period.

(3) There is need for caution in applying the results of this trial directly to local farming practice. In the utilisation of forage crops many farmers follow the practice of *in situ* grazing. This naturally involves the dung and urine of the grazing animals, which return most of the nutrients in the crop, and thus results in much lower soil fertility losses than where the crop is cut and carted off to be fed. However, even with grazing there are gaseous and leaching losses from the droppings, and there are usually considerable within-paddock transfers of nutrients, due to the unequal dropping of dung and urine by the animals.

(4) The results have clearly shown the high immediate residual soil fertility value of good pastures and have also demonstrated how rapidly this fertility can be dissipated through cultivation and cropping. The results agree with the views expressed by Russell[7] and by Jacks[5] who both consider that the residual value of good pastures lasts only for a short time under moist soil conditions. In this trial the combination of the high soil nutrient uptake potential of the crops used, together with the relatively high moisture conditions, is undoubtedly the cause of the very rapid soil fertility exhaustion in the first few months after ploughing of the pastures.

(5) The results of this trial show how essential it is to raise pasture productivity, not only for its own feed value, but also for building up soil fertility for a subsequent crop. The crop yield data show the fallacy

of ploughing poor pasture or undeveloped land for cropping; there is little doubt that such land should be sown with better species and strains of pasture plants and so treated to build up soil fertility before taking a crop. The weakness of double cropping in this climate is also shown except perhaps where the second crop used has a much lower soil nutrient requirement, especially of nitrogen.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance given by Messrs. E. Ennis, R. Brougham, and V. Goodall in the field work, and to Miss S. King for the chemical analyses.

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PASTURE GROWTH AND SOIL FERTILITY

V. THE EFFECTS OF NITROGENOUS FERTILISERS, AND OF "DAY" AND "NIGHT" GRAZING

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(*Received for publication, 26 March 1953*)

Summary

(1) Nitrogenous fertilisers produced no marked differences in the total or seasonal production, and only slight increases in the grass: clover ratio, of ryegrass and white clover pasture growing at Palmerston North, under conditions similar to those of Treatments 2–5 F. R. as described in previous sections of this report. This pasture was producing at the rate of 12,000-14,000 lb. dry matter per acre per annum.

(2) Separate "day" and "night" grazing on such pasture produced marked and rapid changes in production and botanical composition; night grazing induced extra growth, mainly of grass, while day grazing resulted in a lower total production, and a rise in the proportion of clover in the pasture.

(3) Rape crops grown subsequent to this day and night grazing showed marked growth differences in favour of the night grazed area.

Introduction

Parts I-IV of this series presented results of a trial at Palmerston North which demonstrated the increase in soil fertility resulting from clovers and mineral fertilisers, and from the regular return of dung and urine from the grazing animal. The importance of the nitrogen cycle was stressed, and it was estimated that in this trial the annual turnover of nitrogen by the pedigree grass and white clover pastures which received the full and even return of dung and urine from mature dry sheep, was over 600 lb per acre. By comparison, the annual nitrogen uptake of the pure grass swards without dung and urine return, was only some 50 lb per acre. The conclusion was drawn, from the herbage and soil data, that the clovers were essential for their nitrogen fixation, and that the animal dung and urine, produced from the ingested clover dominant herbage, were the main fertilising agencies for grass growth.

The only direct evidence in that trial that nitrogen was in fact of such great importance, was found in the different growth responses to an application of urea applied to all treatments towards the end of the trial period. This nitrogen application (see Fig. 1 in Part II) produced very marked response in grass growth both in the cloverless plots and in the grass-clover N. R. treatments but it produced no visible response in growth on the areas previously in the grass-clover F. R. treatments. It is reasonable to conclude from such evidence when considered with the main data of the experiment, that (a) nitrogen was a major factor in producing the growth difference recorded, and (b) that the soil nitrogen levels were not limiting in the grass-clover F. R. treatments.

The first of these two conclusions agrees of course, with the large body of experimental and practical evidence, all showing the need of grasses for high soil nitrogen, whether supplied by artificials, by clovers, or by animal excrement. Much of the literature on this aspect has been cited in previous sections of this report.

Concerning the second conclusion, there is naturally no general agreement possible on optimum soil nitrogen levels or on the probable responses obtainable from different applications of artificials. These depend so much on the many interactions of climate, plant populations, and current soil nutrient levels, that a full review of the many experimental results secured under different conditions, is not of great value. A recent summary of experimental data, mainly from the U.S.A., has been presented by Ensminger and Pearson[1]. Typical examples of extra grass growth secured in mixed pastures by the application of artificial nitrogen, are found in data of Hughes and Evans[2] and of Walker *et al.*[3] in Britain, of Stewart and Bear[4] in the U.S.A., and of Hudson *et al.*[5] and Rigg and Askew[6] in New Zealand. The New Zealand workers recorded rapid grass responses to artificial nitrogen on pastures of ryegrass, cocksfoot, and white clover, but such responses were usually followed by a "slumping" of pasture growth in the summer periods following the nitrogen applications. This slumping was obviously linked with a depression of clovers in the pasture and was especially pronounced after continued use of sulphate of ammonia.

Other New Zealand trials with artificial nitrogen include those of Sears[7, 8] and Lambert and Thurston[9] who reported considerable increases in seed yields on cloverless stands of ryegrass, of cocksfoot, and of timothy, growing on soils which had been lowered in nitrogen.

The present study was included in this series to measure the effects of relatively heavy winter and early spring applications of artificial nitrogen on pastures of pedigree New Zealand ryegrass and white clover under intensive grazing management in the favourable climatic and soil conditions at Palmerston North.

Another aspect of the soil fertility cycle under grazing conditions is that concerned with the times of grazing and with the return of dung and urine by the grazing animal. It has, of course, been appreciated for a long time that night grazing areas show a rise in soil fertility due to the greater concentration of dung and urine. This is clearly visible on many dairy farms and also on hill country grazings where there is a movement of stock towards night "camping" areas. It has not, however, always been clear whether this is due to a greater proportion of the daily total of dung and urine being excreted at night, or whether it is due to a greater stock concentration on the night grazing area.

In New Zealand Hancock[10] and Levy[11] have estimated that dairy cows normally do about 60 per cent of their grazing during the day. Hancock also estimated from the number of defecations and urinations, that excretion was proportional to grazing, and recommended a balance of grazing areas for dairy herds on this basis. Measurements by Goodall[12] showed, however, that there

is a greater proportion of dung and urine passed at night, due to the greater size of urinations and defecations during the night than the day. No similar data are available for sheep but from the dung and urine collections made in the present experiment a similar disparity appeared to exist between ingestion and excretion, a greater proportion being passed during the night periods than during the day periods.

Field measurements of the effects of such differential day and night excretions have been published by Stapledon and Davies[13]. They showed very marked increases in the pasture growth on the night paddock relative to the day paddock rising in one year to a threefold difference in the mid-season period. The present experiment was carried out to determine the effect of grazing in separate day and night paddocks on highly fertile soil where clovers are able to grow vigorously.

Experimental Methods

Nitrogenous Fertiliser Trial

The area was the 1/10th acre paddock adjacent to the Mowing and Grazing series of the main experiment. This was sown at the same time with the same seed mixture as used for Treatments 2–5, and grazings and the return of dung and urine were carried out on the same basis and at the same times. An overall fertiliser treatment of 4 cwt superphosphate, and 5 cwt lime per acre was applied each autumn.

The plot layout for the nitrogen treatments was the same as for the grazing series of the main experiment, the treatments being as follows:

(1) Control—no nitrogen applied;

(2) Sulphate of ammonia in mid-June;

(3) „ „ „ ½ in June, ½ in August;

(4) „ „ „ in mid-August;

(5) Nitrate of Soda in mid-June;

(6) „ „ „ ½ in June, ½ in August.

No applications were made until the second year, by which time the pasture was well established. The rates of application of both fertilisers were 2 cwt per acre in 1947, and 4 cwt per acre in 1948 and 1949.

Yields and botanical composition were determined as for the grazing series of the main trial; no chemical analyses of the herbage or soil were made.

Day-and-night grazing trial

Two 1/10th acre paddocks were used; the first was on the eastern boundary of the grazing series, and had been sown at the same time and with the same mixture as for Treatments 2–5 of the main experiment; the second was the paddock which was used for

the nitrogenous fertiliser trial until the end of 1949. The first paddock had been rotationally sheep grazed between 1946 and August 1948. At the latter date the pasture growth appeared to be very uniform, and was producing at the same level as, and with a botanical composition very similar to, Treatments 2–5 F. R. of the grazing series. This paddock was then fenced into two equal areas. Between September 1948 and June 1950 one half was grazed only between 8 a.m. and 4.30 p.m., the sheep being shifted to the other half for the remaining part of each day. Each grazing took from 3 to 4 days and care was taken to alternate the areas into which the sheep were brought at each grazing, this being done to spread equally any carryover of dung and urine to and from the total area. After November 1950, the grazings were reversed; all the growth between July and November 1950 was cut and discarded from the area in order to reduce any carry-over effect from the first period of differential grazing. The treatment then continued until September 1951.

Herbage measurements were made by the use of caged enclosures each 10 ft x 4 ft, which were moved to fresh places in each paddock prior to each grazing. The herbage within each cage was cut with hand shears at the end of each grazing, down to the grazed height of each area. Both areas were trimmed by mower occasionally after the grazings to maintain a constant defoliation level, and also for the even spreading of dung, more especially needed on the night grazing area.

The second area was divided for separate day and night grazing on 8 January 1950 after the nitrogen trial had finished and the whole area had been open grazed for two months. Sixty per cent of the area was enclosed for day grazing and 40 per cent for night grazing, as this division agreed better with animal ingestion habits[9].

The grazing hours were the same as for the first paddock as also were the measurement methods. The grazings continued until September 1951. No reversal of treatments was applied but at the end of the grazing period the whole area was cultivated and sown with rape. This coincided with the sowings on the mowing series, and cultivation and harvest of the crops on the two areas were carried out similarly. Eight complete rows of rape were separately measured in the area previously under the day-grazing treatment, and six complete rows in the night area.

RESULTS

Nitrogenous fertiliser trial

The growth over the total plot area was very similar throughout to that in Treatments 2–5 of the Grazing F. R. series of the main experiment. There were, however, some small visible differences on the nitrogen treated plots; on these there was a slightly greater grass growth which developed about 2 weeks after the nitrogen applications and which persisted for about 6 weeks. No marked "slumping" of the total pasture growth or depression of clover later in the season was seen.

TABLE I. EFFECT OF ADDED NITROGEN ON GRASS AND CLOVER GROWTH
(yields in hundreds lb. D.M. per acre)

Season and Growth Period	1 Control			2 S/A in June			3 S/A in June and August			4 S/A in August		
	Grass	Clover	Total	Grass	Clover	Total	Grass	Clover	Total	Grass	Clover	Total
Establishment March 1946 - 16 6 47	69	31	100	66	30	96	68	29	97	68	32	100
Winter 16 6 47 - 1 9 47	7	4	11	9	3	12	8	3	11	6	4	10
Spring 1 9 47 - 17 11 47	22	11	33	21	10	31	21	11	32	22	10	32
Summer 17 11 47 - 16 2 48	8	23	31	8	19	27	9	18	27	8	17	25
Autumn 16 2 48 - 14 6 48	6	9	15	6	8	14	6	9	15	7	8	15
Total 16 6 47 - 14 6 48	43	47	90	44	40	84	43	41	84	43	49	82
Winter 14 6 48 - 30 8 48	11	6	17	14	4	18	13	4	17	9	5	14
Spring 30 8 48 - 23 11 48	33	10	43	39	6	45	37	7	44	36	7	43
Summer 23 11 48 - 14 3 49	21	26	47	22	26	48	24	26	50	24	24	48
Autumn 14 3 49 - 30 5 49	10	5	15	9	6	15	10	6	16	11	5	16
Total 14 6 48 - 30 5 49	75	47	122	84	42	126	84	43	127	80	41	121
Winter 30 5 49 - 22 8 49	11	3	14	13	2	15	13	2	15	14	2	16
Spring 22 8 49 - 18 11 49	29	15	44	36	10	46	42	8	50	36	10	46
Total 30 5 49 - 18 11 49	40	18	58	49	12	61	55	10	65	50	12	62

TABLE I. (continued)

	5 N/S in June and August			6 N/S in June			Treatments 3 and 5 Grazing F. R. in Main Experiment		
	Grass	Clover	Total	Grass	Clover	Total	Grass	Clover	Total
Establishment March 1946 - 16 6 47	67	31	98	63	30	93	64	33	97
Winter 16 6 47 - 1 9 47	9	3	12	9	3	12	6	4	10
Spring 1 9 47 - 17 11 47	21	11	32	20	9	29	20	15	35
Summer 17 11 47 - 16 2 48	7	20	27	9	16	25	7	21	28
Autumn 16 2 48 - 14 6 48	7	9	16	7	8	15	6	11	17
Total 16 6 47 - 14 6 48	44	43	87	45	36	81	39	51	90
Winter 14 6 48 - 30 8 48	12	5	17	12	4	16	13	5	18
Spring 30 8 48 - 23 11 48	36	9	45	33	10	43	35	11	46
Summer 23 11 48 - 14 3 49	21	27	48	24	23	47	26	24	50
Autumn 14 3 49 - 30 5 49	11	5	16	10	6	16	13	5	18
Total 14 6 48 - 30 5 49	80	46	126	79	43	122	87	45	132
Winter 30 5 49 - 22 8 49	14	2	16	12	2	14	9	2	11
Spring 22 8 49 - 18 11 49	35	11	46	35	10	45	34	13	47
Total 30 5 49 - 18 11 49	49	13	62	47	12	58	43	15	58

Table I presents the yields of grass and clover for each treatment, arranged in periods as near to the normal seasons as the cutting dates allowed. Also shown for comparison are the mean yields of Treatments 3 and 5 of the grazing F. R. series of the main experiment. It can be seen that:—

(1) Both in yield and botanical composition, the control treatment of this experiment was very similar to the corresponding treatment of the main experiment; the botanical composition of the total herbage in both trials was close to 60 per cent grass and 40 per cent clover, the grass being ryegrass with only very small amounts of cocksfoot and other species, and the clover being white clover with a small amount of red clover in the first year of the trial.

(2) There were negligible differences in total yields between treatments.

(3) In the second and third winter and spring periods there were increases in grass growth, with corresponding decreases in clover growth, on the nitrogen treatments, more especially from the sulphate of ammonia. All differences were however, small.

Day and Night Grazing Trial

In both sets of paddocks there were rapid and marked changes in pasture herbage yield and composition. Table II presents the herbage yields for both areas, divided into convenient sub-periods. It can be seen that:

(1) Total herbage yields showed a progressive relative increase under the night grazing. This was also clearly visible in the individual cuts.

(2) Changes in species yields were very marked in both areas, the night grazing encouraging ryegrass growth relative to the clover and other grasses (mainly cocksfoot and browntop), and the reverse applying under the day grazing treatment.

(3) The treatment effects were similar after the reversal on the 50 : 50 area but in this case there was a temporary increase in the growth of cocksfoot on the area previously in day grazing, where the cocksfoot had increased after the decline of the ryegrass.

(4) On the 60:40 area there were differences in the yields of rape grown on the two areas very similar to the differences in previous pasture yields under the day and night grazing. The data from the previous nitrogen trial had shown there was no difference in yield potential between the two areas at the start of this trial. An F test was therefore valid and showed the rape crop yield difference to be highly significant (P .001.)

TABLE II. EFFECT OF DAY AND NIGHT GRAZING ON PASTURE AND SUBSEQUENT CROP YIELDS

Paddock - Treatment	Growth Period	Grazing Times	Herbage Yields (000's lb D.M. acre)				Relative Yields Day = 100
			Ryegrass	Other Grasses	White Clover	Total	
50% of area grazed "Day" only and 50% "Night" only. Treatments reversed after 2 years	8.9.48 - 11.8.49	Night	86	8	43	137	136
		Day	60	7	34	101	100
	11.8.49 - 28.6.50	Night	109	7	20	136	143
		Day	55	12	38	95	100
	28.6.50 - 28.11.50	All herbage cut and discarded					
	28.11.50 - 7.9.51 Reversed Treatment	Day	49	8	11	68	100
		Night	61	25	10	96	141
60% of area "Day" grazing only and 40% "Night" grazing only. Rape crop grown subsequent to 2 years treatment	8.11.50 - 31.8.50	Night	39	21	26	86	115
		Day	25	12	38	75	100
	31.8.50 - 6.9.51	Night	83	33	16	132	144
		Day	23	36	33	92	100
	1.2.52 Subsequent Rape Crop	Night area	Rape - total herbage			68	158
		Day area	" " "			43	100

DISCUSSION

The main item of interest is the minimal responses recorded to the relatively high applications of nitrogen. These have, however, followed a pattern similar to that reported by Hudson[5]. The difference in degree of response and "slumping" between this trial and those of Hudson is possibly due to several factors, among which would be:

(a) In this trial there was apparently no limitation for soil minerals. By contrast, Hudson's trials showed responses to superphosphate even under normal grazing conditions with the return of dung and urine. It would therefore be expected that under his conditions the extra growth from added nitrogen would emphasise any mineral shortage. This would also be greater under his technique where the herbage was completely removed, or if any fertility transfer from plot to plot, by the grazing animal, took place.

(b) In this trial the soil nitrogen levels were probably higher than in Hudson's trials due to the improved white clover strains now in use:

(c) The soil moisture position appeared to be satisfactory throughout this trial, due to the weather and to the high soil organic matter:

(d) Care was taken throughout this trial to mow and graze the plots before there was any obvious shading of the clover.

It is of interest, in considering this last factor, to note the recent results of Walker *et al.*[3] who recorded high responses to artificial nitrogen in silage crops from pastures low in clovers, but only small increases in pastures with a high clover content. In the latter pastures the extra grass growth from added nitrogen only compensated for lowered clover yields, and Walker drew attention to the need for care in the use of nitrogen on such swards, and in subsequent cutting and grazing, to maintain the desired balance of grass and clover. The marked responses to nitrogen reported by Hughes and Evans[2], and Rigg and Askew[6] were obtained on relatively low-producing pastures.

The results of the grazing trial clearly show that the full return to the pasture of the dung and urine passed by the animals grazing the pasture, has been of major importance in maintaining the soil fertility. The results agree with those reported by Stapledon and Davies[13], with field observations on New Zealand farms, and also with estimates obtained from the data from previous trials at this station on the effects of dung and urine on pasture[14], [15], and from Goodall's data on the amounts of dung and urine passed by dairy cows during day and night[12]. In both paddocks of the present trial there were rapid and obvious increases in the ryegrass and total growths under the night grazing. Under day grazing there was development of clover dominance and an increase in grasses other than ryegrass. By comparison with the main experimental results, the pasture development under day grazing was intermediate between the N. R. and the F. R. grass and clover series; the night grazing pasture showing an even greater development towards grass dominance than the F. R. series. Such increase in grass dominance, over the composition of the F. R. grass and clover series, may have been due either directly to the greater soil fertility and additional grass growth induced by the extra dung and urine passed during the night, to death of clover either by a direct chemical effect of the extra urine[16] or by the physical hoof action of the extra stocking intensity, or to a combination of these. The subsequent large differences in the rape crop growth suggest strongly, however, that the transferred dung and urine was a major factor.

The results of the two trials fit well into the main pattern of pasture development as demonstrated by the results of the major series; the results support the conclusions drawn that, with the use of the pedigree white clover, adequate soil minerals, and a suitable soil and climate, and also under the regular defoliation and dung and urine return conditions of this trial, the soil nitrogen is maintained at the optimum level. Rapid and marked changes can, however, be induced by a modification in the grazing and return of dung and urine.

In this experiment it is highly probable that the critical nutrient in the excreta was nitrogen. This position will of course, not apply generally, as undoubtedly there will also be considerable pressure on other nutrients in other soils and under different farming practices.

Similarly, the position of the different nutrients would no doubt be different under a longer period of such differential grazing; a variation in the actual grazing periods would no doubt also produce different results.

An appreciation of the general principles involved is, however, of obvious importance in farming practice and also in pasture experimental work. In farming practice a variation in grazing times can be used to increase or decrease soil fertility and to effect changes in botanical composition. For most farm grazing routines and for pasture field trials it seems obvious, however, that a complete daily cycle of grazing is necessary. The matter will be discussed further in Part VII.

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